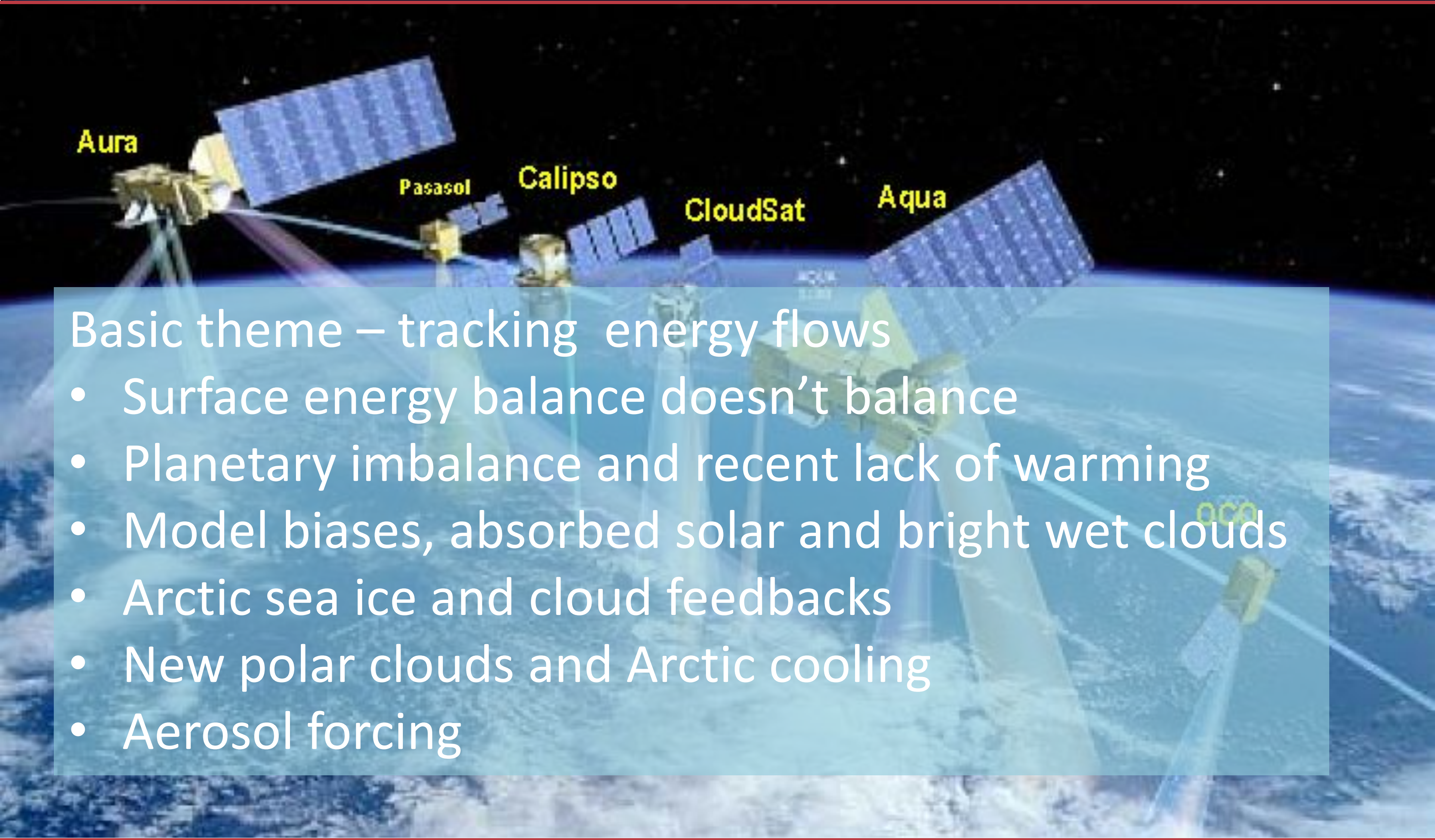
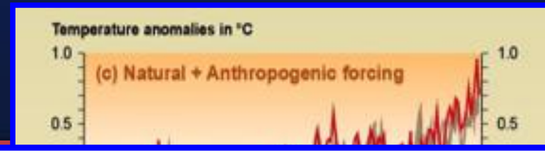
# A-Train: addressing climate imperatives




Basic theme – tracking energy flows

- Surface energy balance doesn't balance
- Planetary imbalance and recent lack of warming
- Model biases, absorbed solar and bright wet clouds
- Arctic sea ice and cloud feedbacks
- New polar clouds and Arctic cooling
- Aerosol forcing

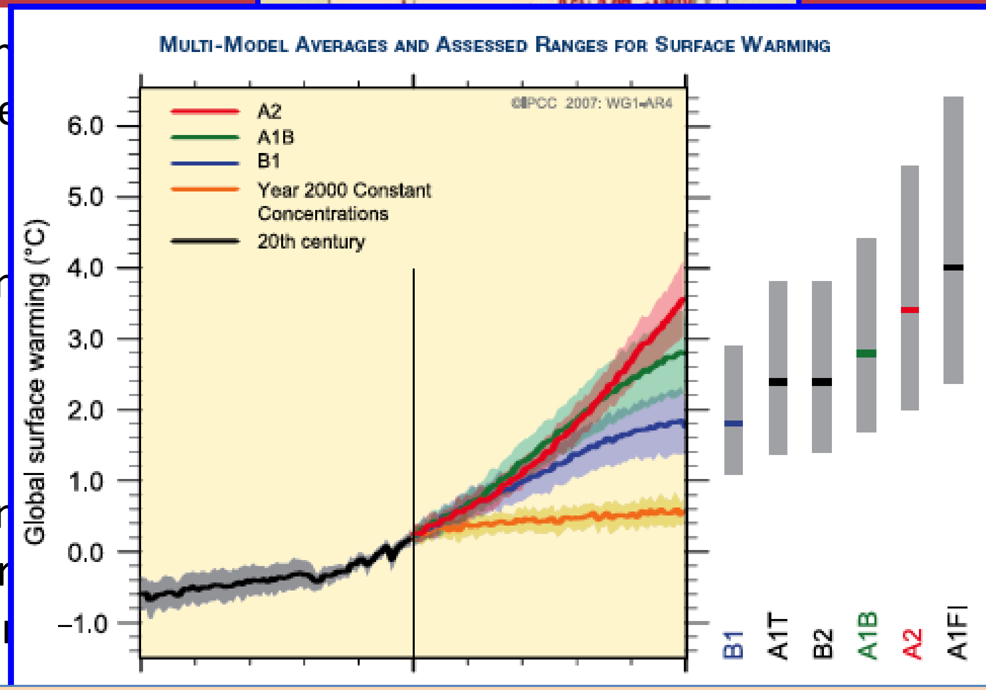
# One of the roles of  satellite obs



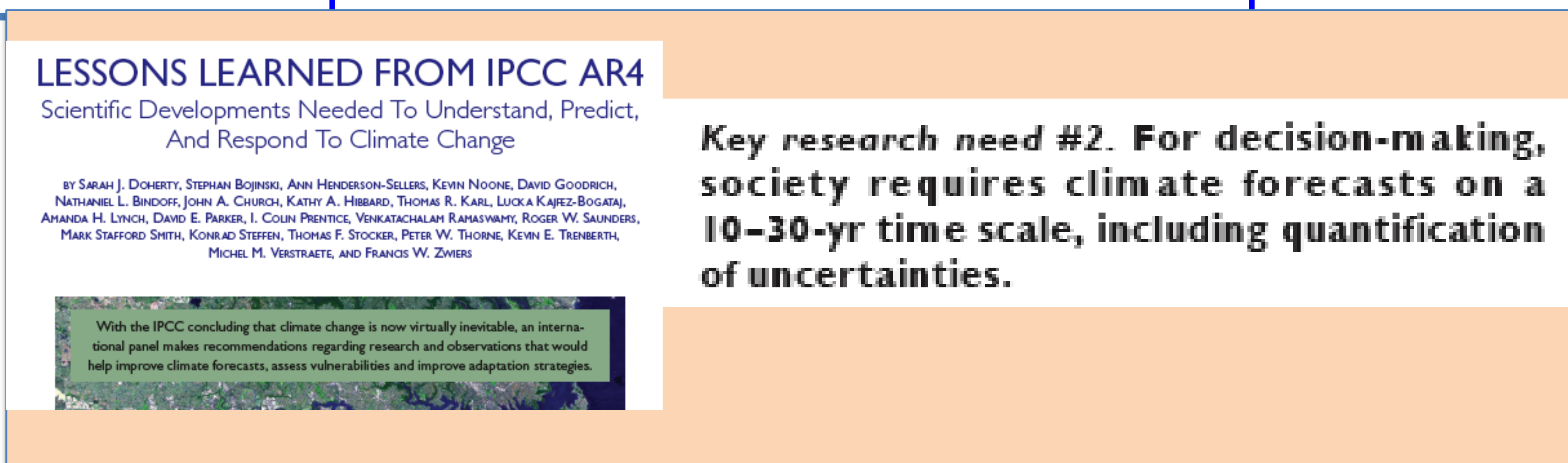
•To develop an understan… the important earth-syste… processes

•To test this understandin… predictive models of the … system

•To apply these models in… projections important for … adaptation and mitigation…







LESSONS LEARNED FROM IPCC AR4

Scientific Developments Needed To Understand, Predict, And Respond To Climate Change

BY SARAH J. DOHERTY, STEPHAN BOJINSKI, ANN HENDERSON-SELLERS, KEVIN NOONE, DAVID GOODRICH, NATHANIEL L. BINDOFF, JOHN A. CHURCH, KATHY A. HIBBARD, THOMAS R. KARL, LUCKA KAJFEZ-BOGATAJ, AMANDA H. LYNCH, DAVID E. PARKER, I. COLIN PRENTICE, VENKATACHALAM RAMASWAMY, ROGER W. SAUNDERS, MARK STAFFORD SMITH, KONRAD STEFFEN, THOMAS F. STOCKER, PETER W. THORNE, KEVIN E. TRENBERTH, MICHEL M. VERSTRAETE, AND FRANCIS W. ZWIERS

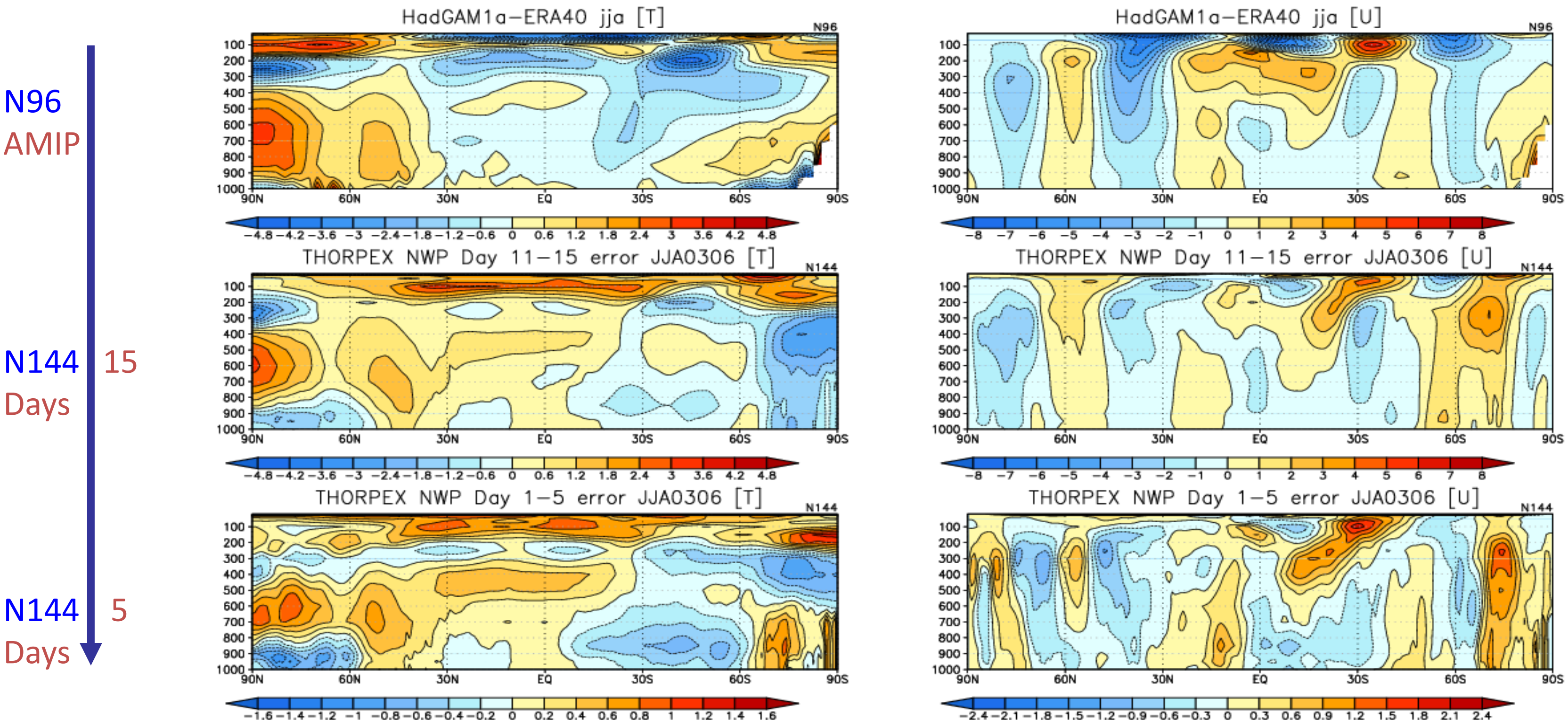
With the IPCC concluding that climate change is now virtually inevitable, an international panel makes recommendations regarding research and observations that would help improve climate forecasts, assess vulnerabilities and improve adaptation strategies.

***Key research need #2.*** **For decision-making, society requires climate forecasts on a 10–30-yr time scale, including quantification of uncertainties.**

public opinion/action & policy.

# Example of model bias UKMO zonal T & u biases

The key model uncertainties form early and persist throughout the integration.   These effects then dwarf other sources of uncertainties on the 10-30 year time frame considered critical for decision support.




UKMO zonal T & u biases

(Williams, per communication) Transpose -amip

# A-Train and the planet's energy balance

Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

ELSEVIER

**An imperative for climate change planning: tracking Earth's global energy**

Kevin E Trenberth

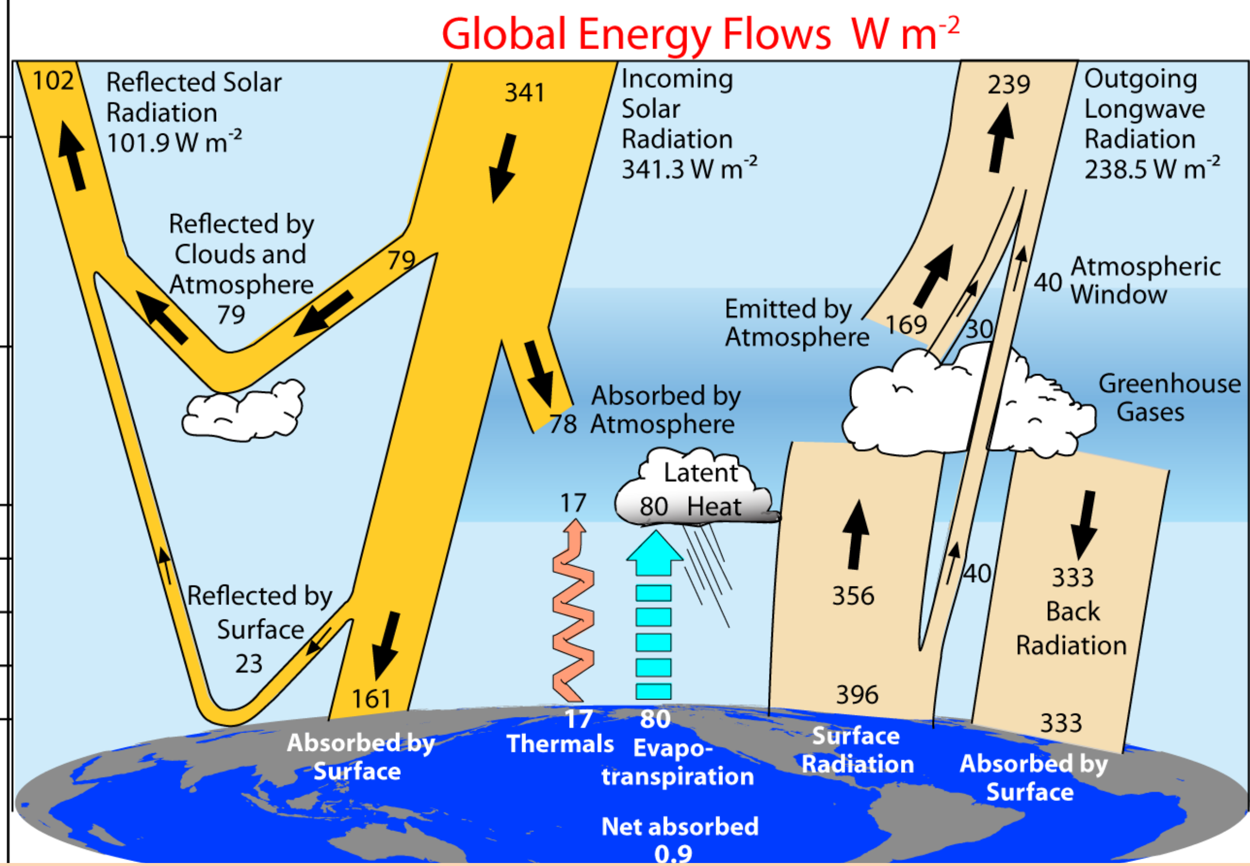
•A-Train observations have become a key anchor point for other important (and longer) data records (cloud climatolgies, surface energy budget climatologies, ..)

•A-Train observations have become essential for diagnosing current changes to the planet's energy balance & 'tracking' how energy flows through the system

•A-Train observations have sharpened our understanding of where major sources of uncertainty exist in our view of the planets energy balance

•These observations are now identifying sources of key model biases

| | All Sky | | | Clear Sky | | |
|---|---|---|---|---|---|---|
| | LW up | LW dn | LW net | LW up | LW dn | LW net |
| CERES SRBAVG-GEO | | | | | | |
| Model A | | | | | | |
| Model B | 392 | 344.1 | -47.9 | | | |
| CERES SYN/AVG/ZAVG | | | | | | |
| Untuned | 397.9 | 342.2 | -55.7 | | | |
| Tuned | 398.1 | 342.1 | -56 | | | |
| SRB | | | | | | |
| GEWEX ( | 397.1 | 342.9 | -54.2 | | | |
| QC | 399.1 | 348.7 | -52.4 | | | |
| ISCCP ( | 393.7 | 345.4 | -48.3 | | | |
| NCEP reanalysis | 397.4 | 340.4 | -57 | | | |
| ERA-40 | 396.2 | 341.2 | -55 | | | |
| Wild et al., | | | | | | |
| Trenberth et al (2009) – 2000-2005 | 396 | 333 | -63 | | | |
| A-Train – 2006-2009 | | | | | | |
| Radar+Lidar (L) | 399±7 | | | | | |
| Radar+Lidar (K) | 404.3 | | | | | |
| Radar+Lidar (K)-scaled | 399.1 | | | 398.2 | 316.0 | -82.2 |



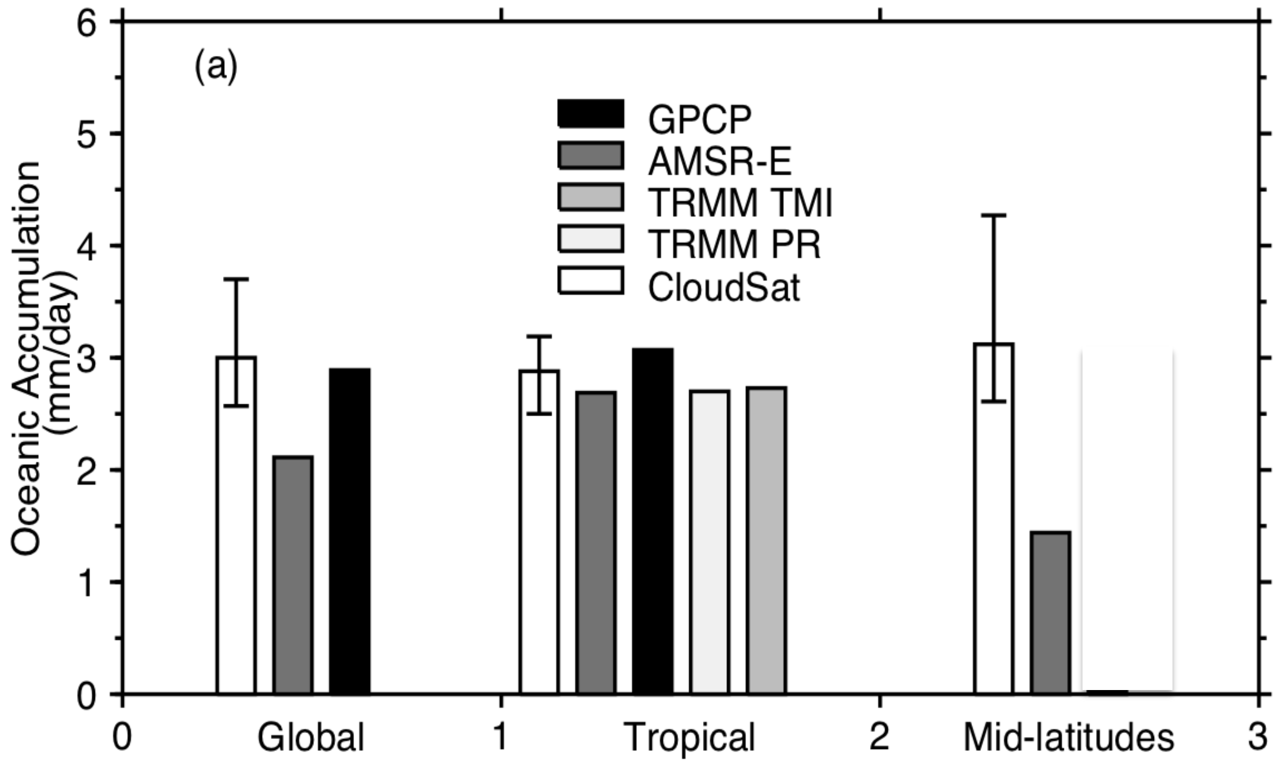

349

353

350

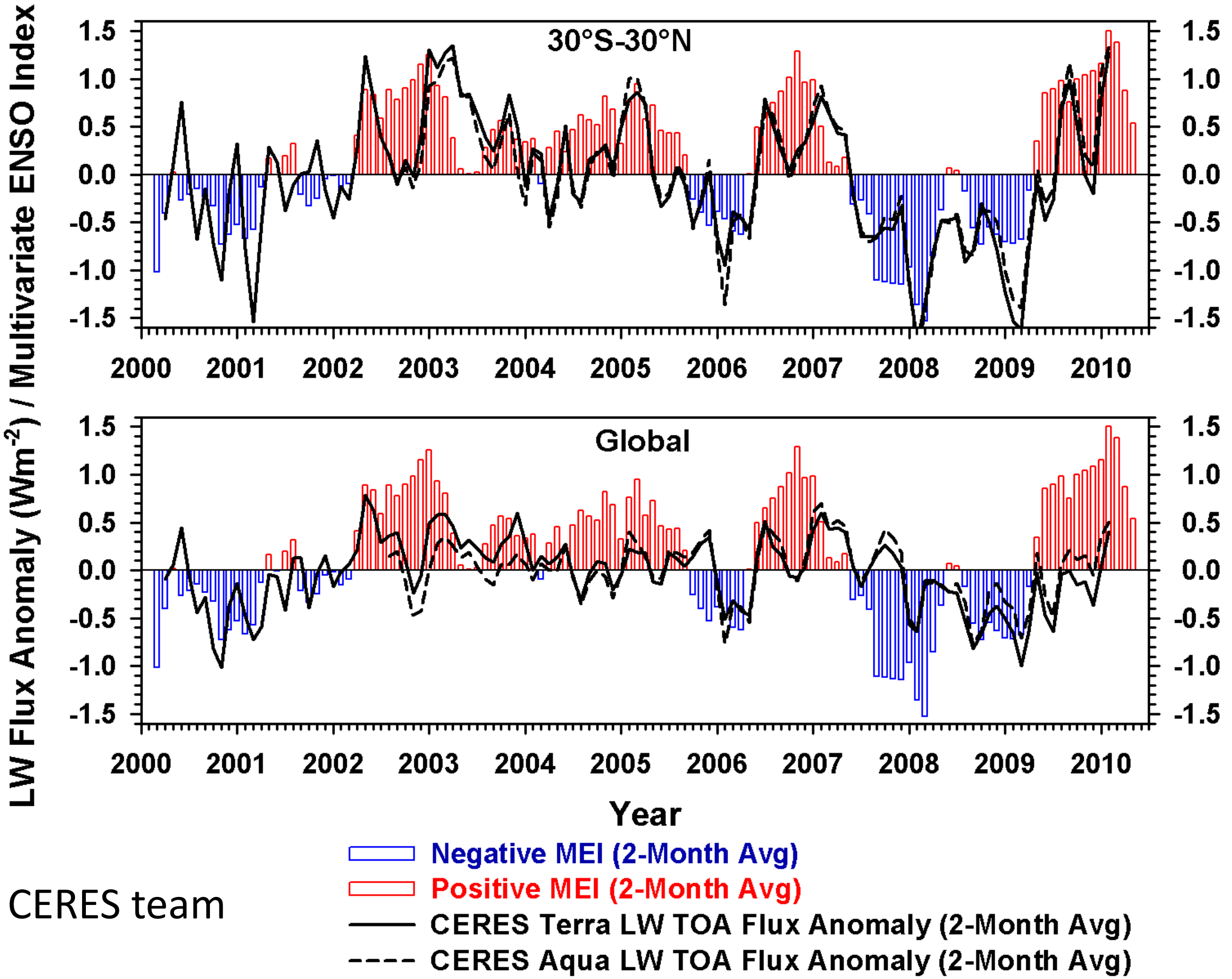
A-train data (Cloudsat, CALIPSO, MODIS, AIRS, CERES combine to confirm major discrepancies between 'model' and data suggesting a major gap in our current understanding of the surface energy balance

# Rainfall accumulation

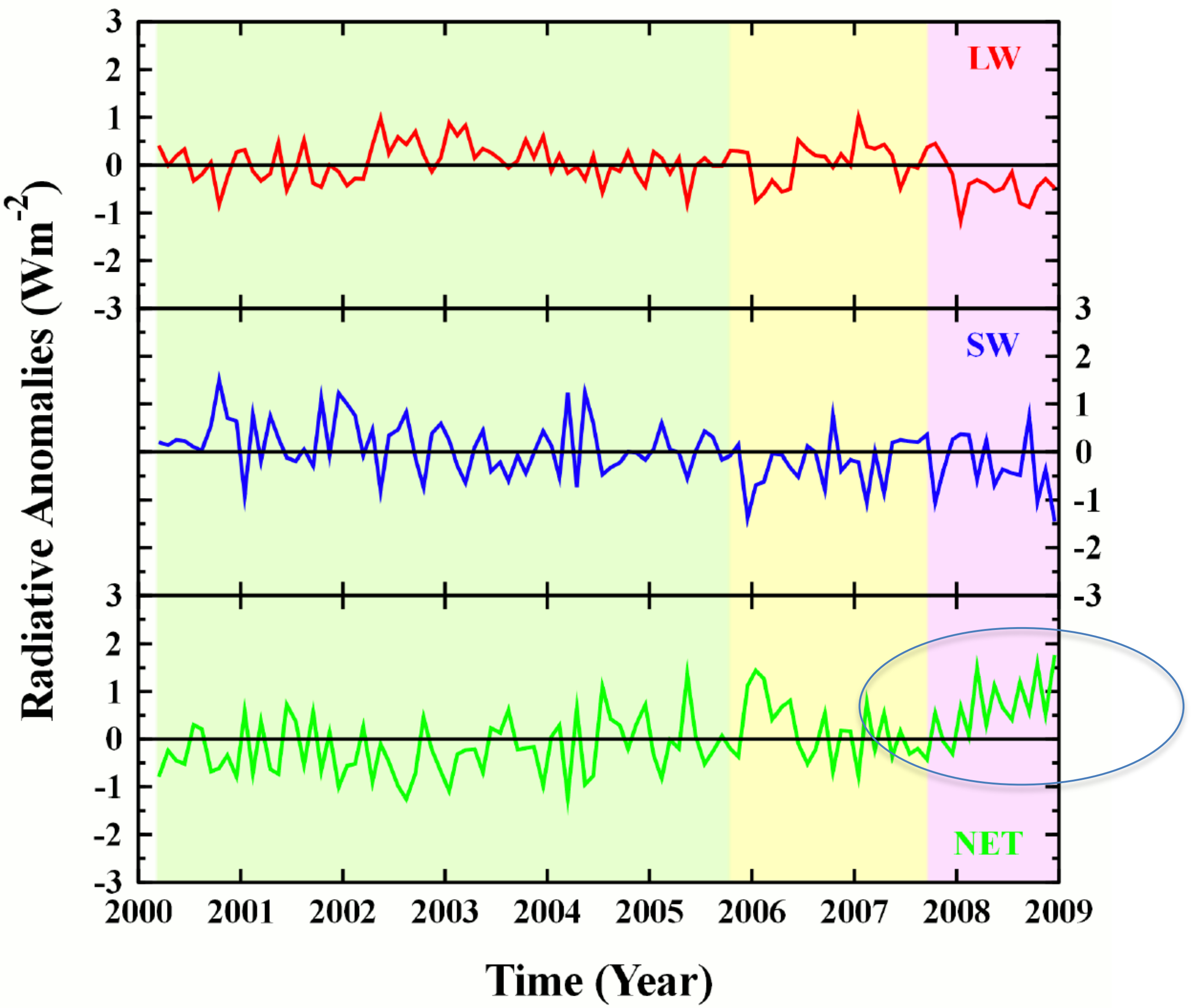



The mid-latitudes appear to be much rainier than previously thought

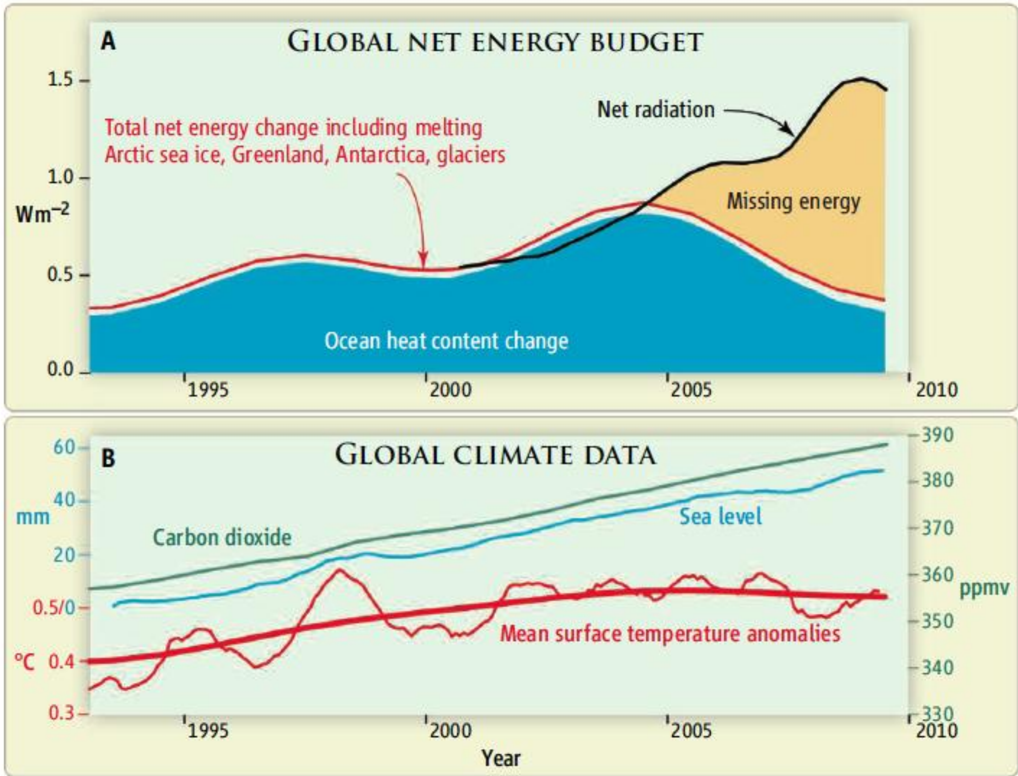
# Tracking energy: Our warming planet?



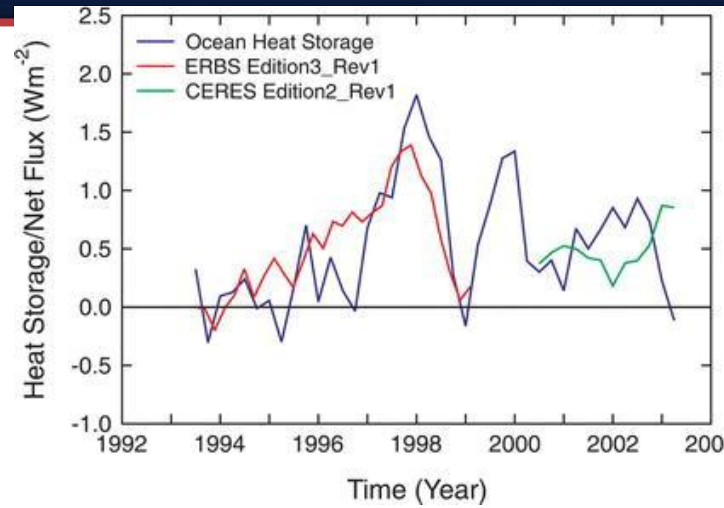

Loeb and the CERES team


LW
SW
NET
Radiative Anomalies (Wm^-2)
Time (Year)
3
2
1
0
-1
-2
-3
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

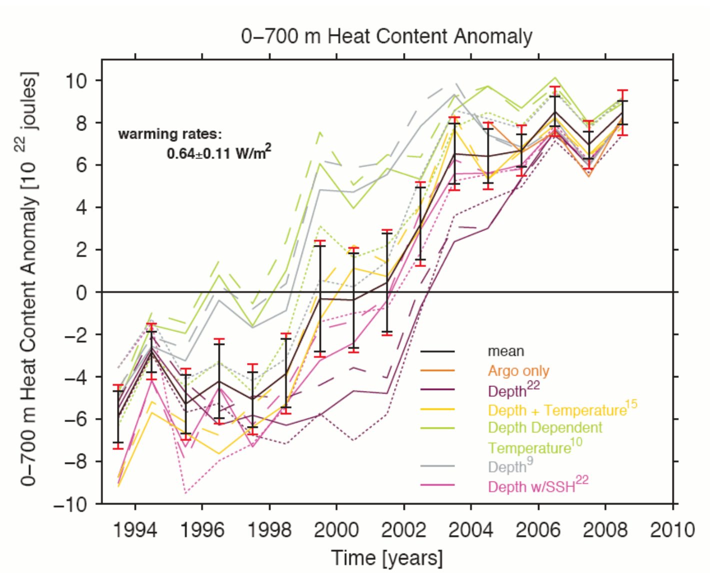
# The energy imbalance – where has it gone?




Trenberth 2010

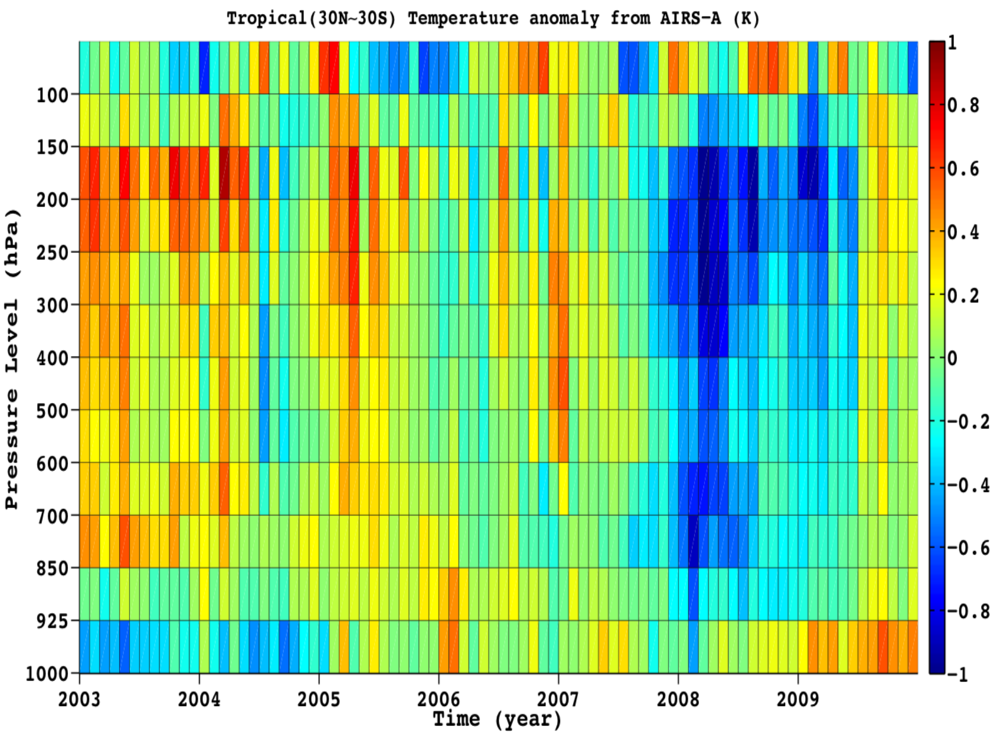



Wong et al., 2006

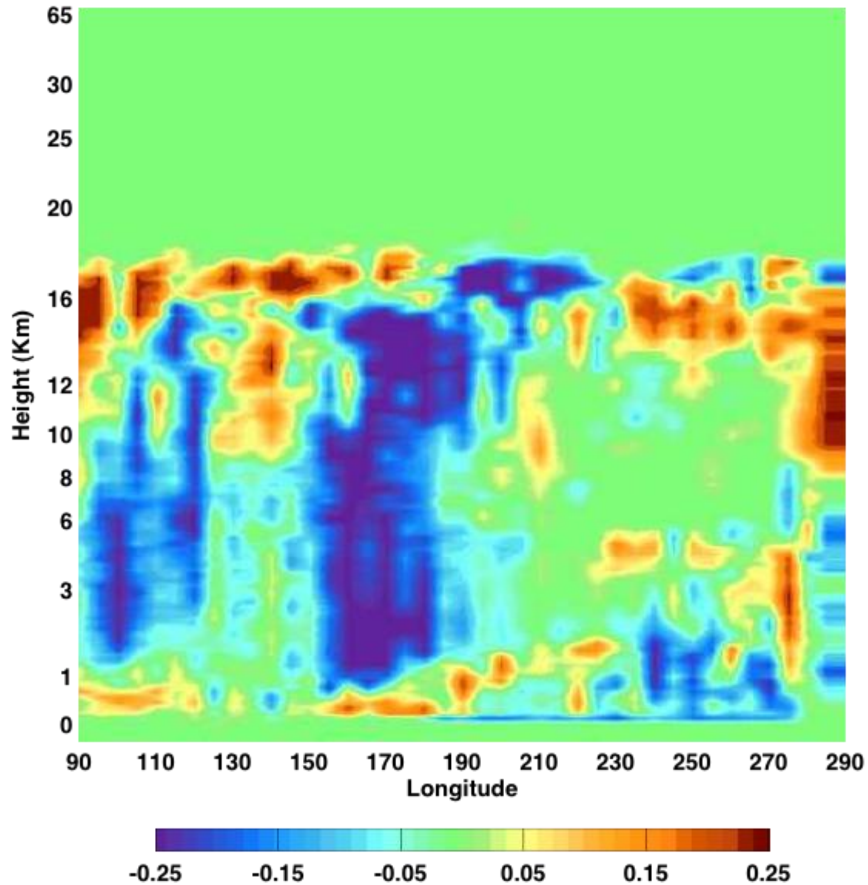



Lyman et al., 2010

## AIRS Temperature Anomaly (30°S-30°N)

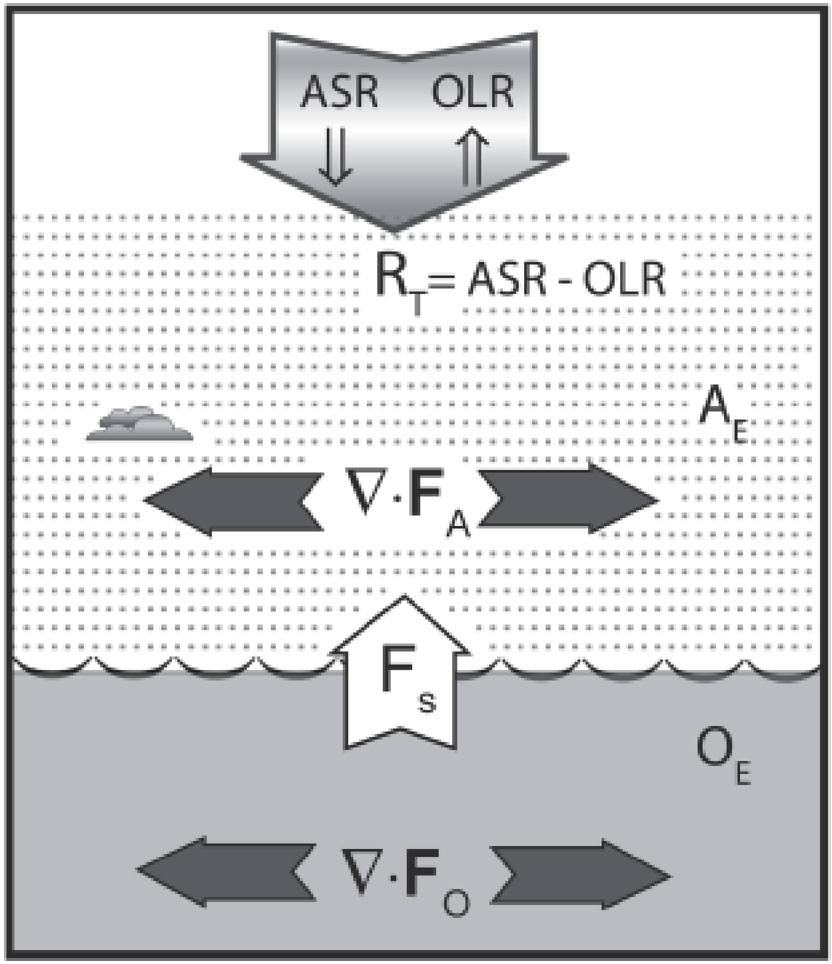


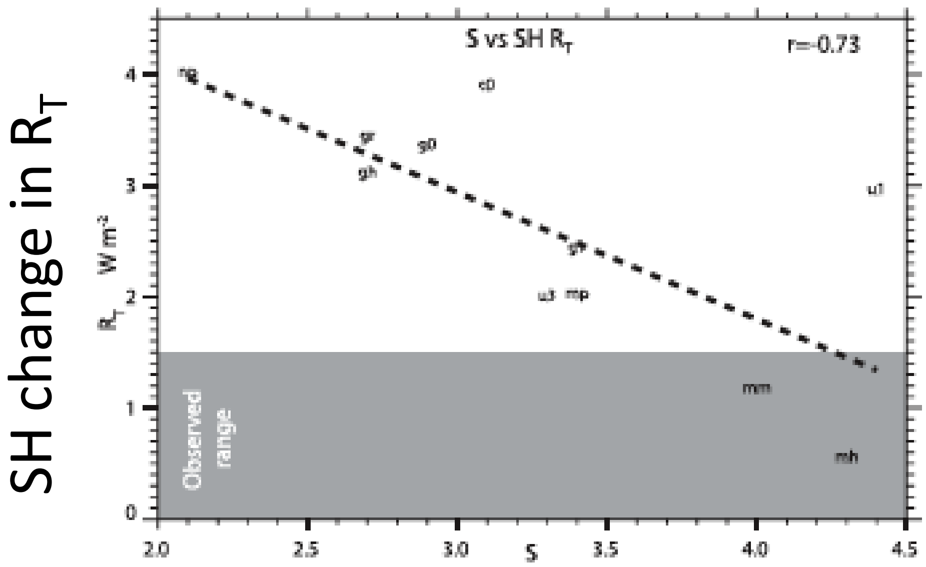

## Cloud Frequency of Occurrence Difference Jan08 minus Jan07 (0S–2.5S)




Major atmospheric occurred during the El Nino /La Nina

# Heat input and transport



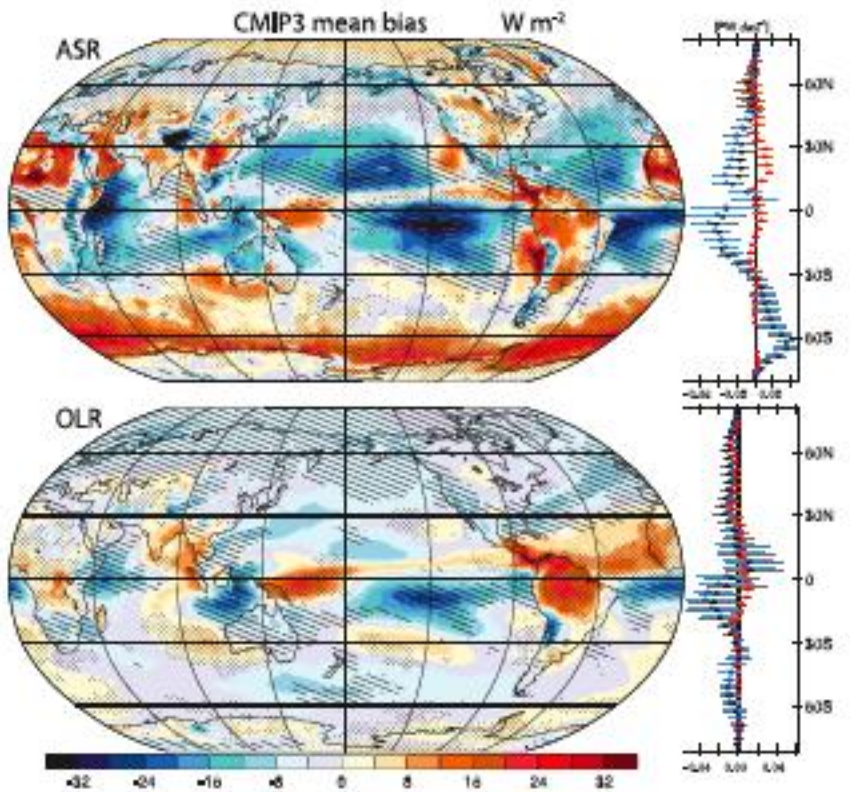




Climate Sensitivity

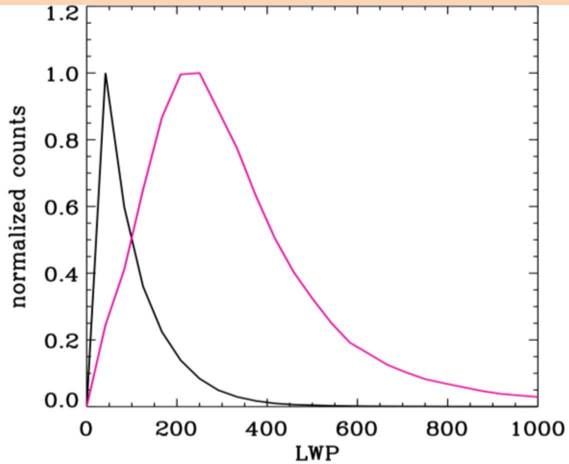
Trenberth & Fusullo, 2010

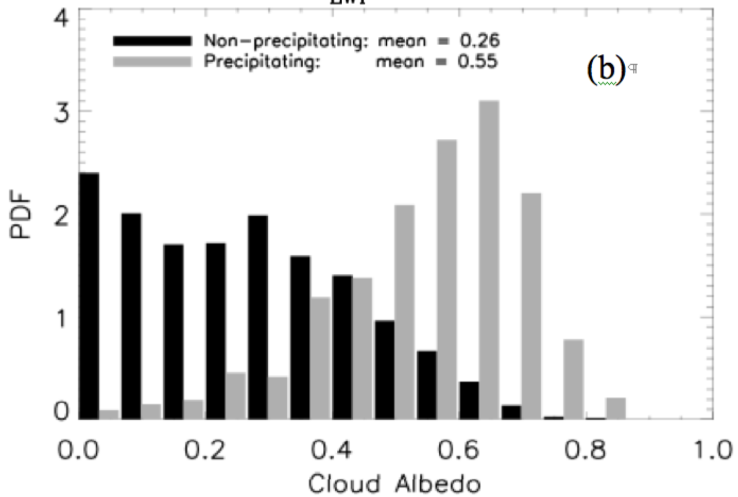
# The TOA absorbed solar bias

Precipitating clouds are significantly brighter than non-precipitating clouds

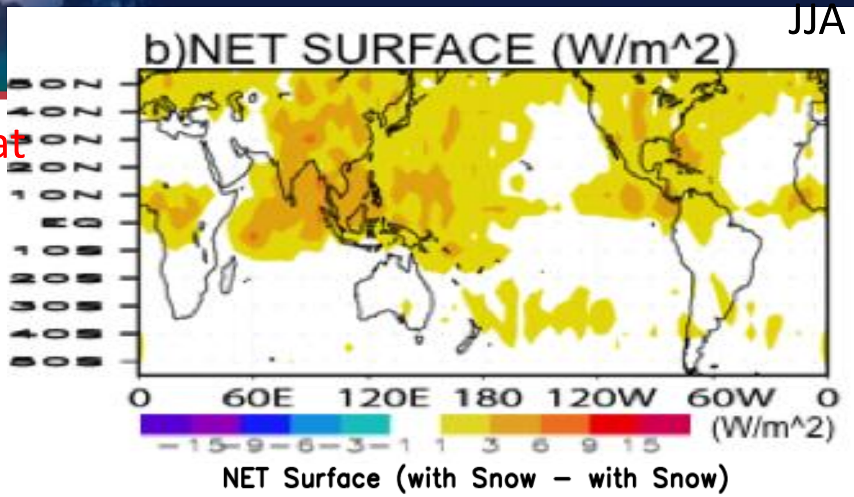



Trenberth & Fusullo, 2010



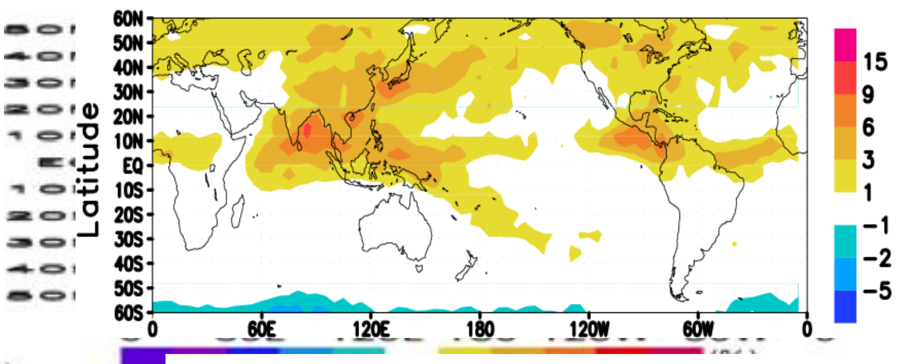



CloudSat offline

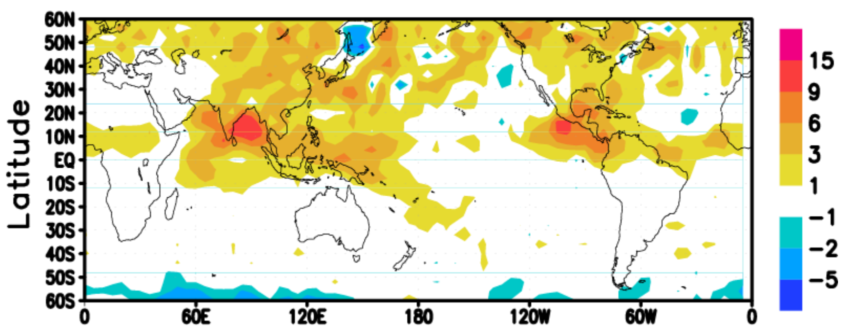



**(Waliser, Li and L'Ecuyer, 2010)**

EC FCST 24to48




EC FCST 120to240

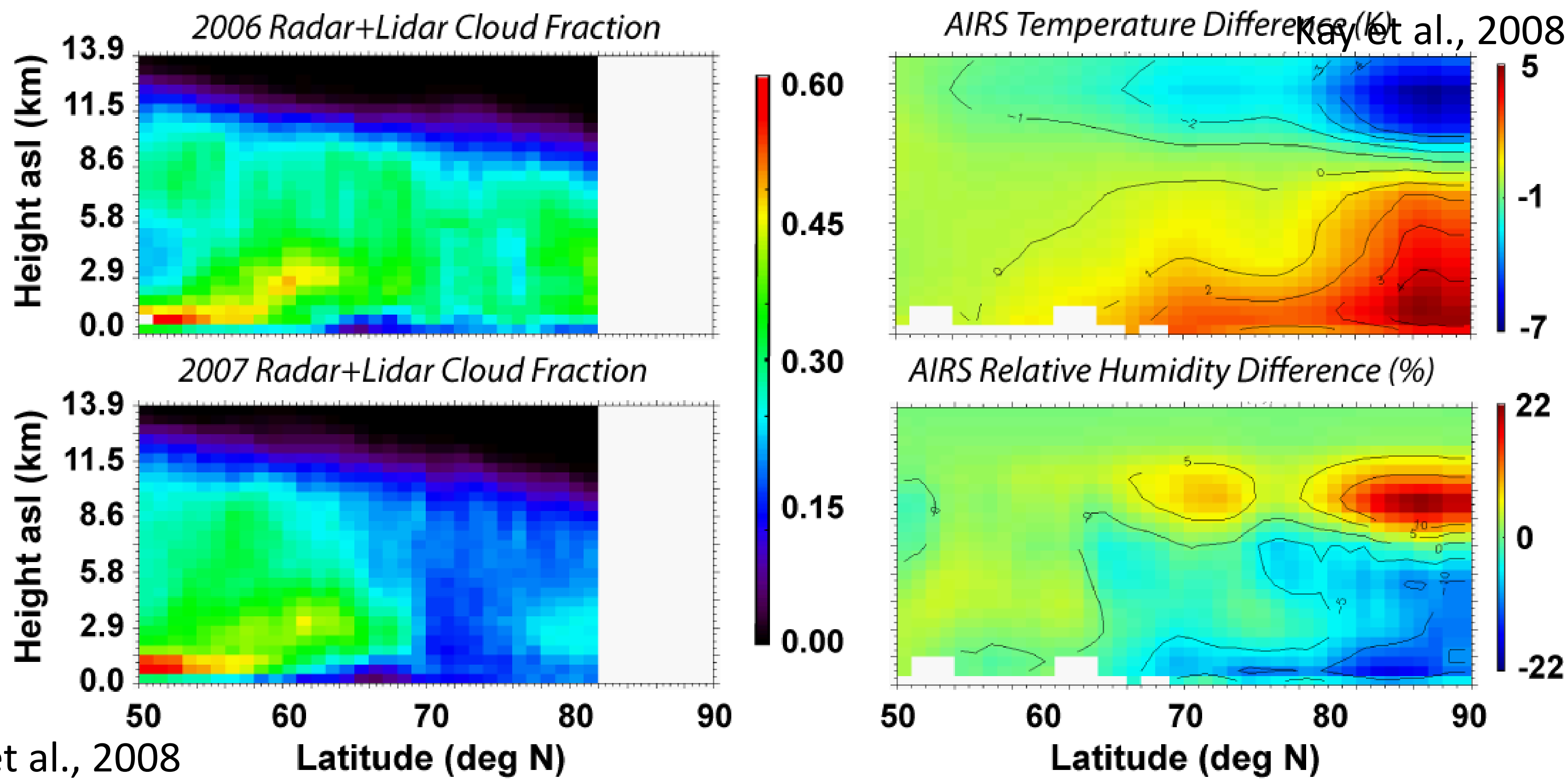



Differences are no snow (precipitation) – control (with snow)

Positive vales mean snow significantly reduced radiation fluxes at surface=more reflections & reduced absorbed solar

**(Li, Waliser and Forbes, 2010)**

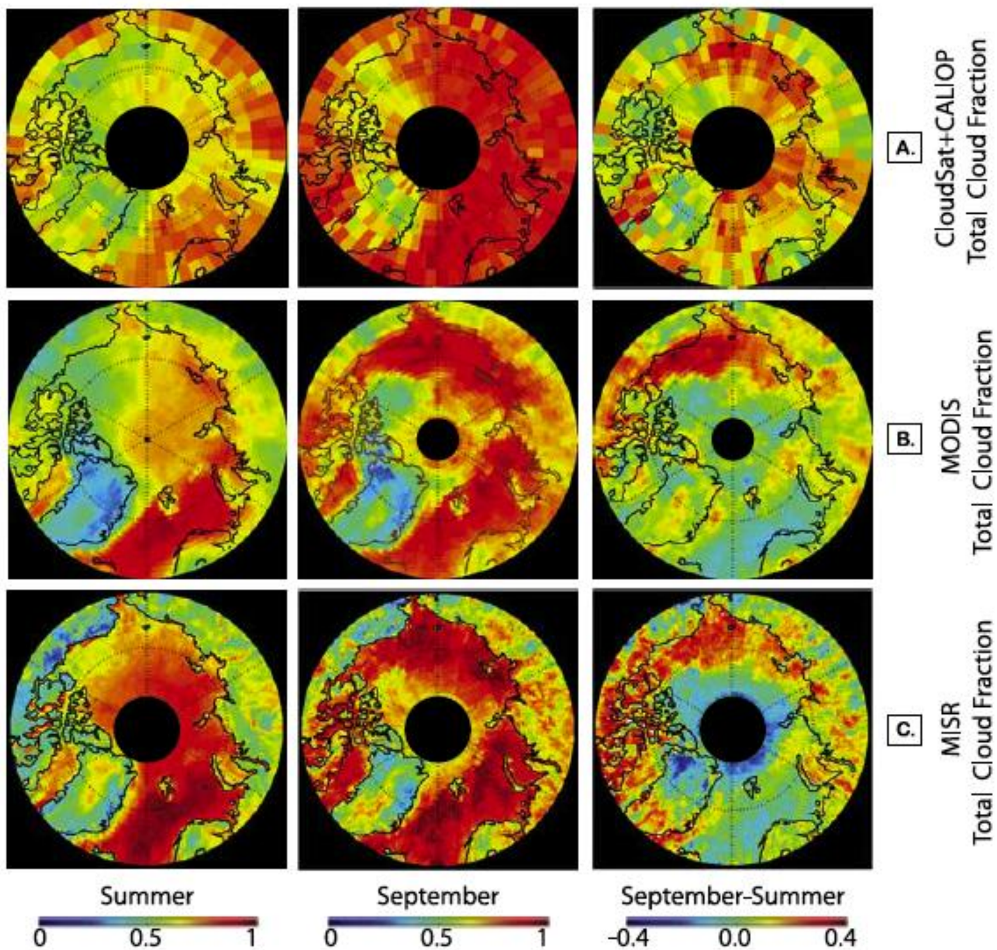
# The Arctic energy balance & sea ice loss




Kay et al., 2008

Kay et al., 2008

*A-train data reveal dramatic cloudiness reductions, T increases, and RH decreases associated with the 2007 circulation anomalies resulting in a substantial heating of the Arctic Ocean.*



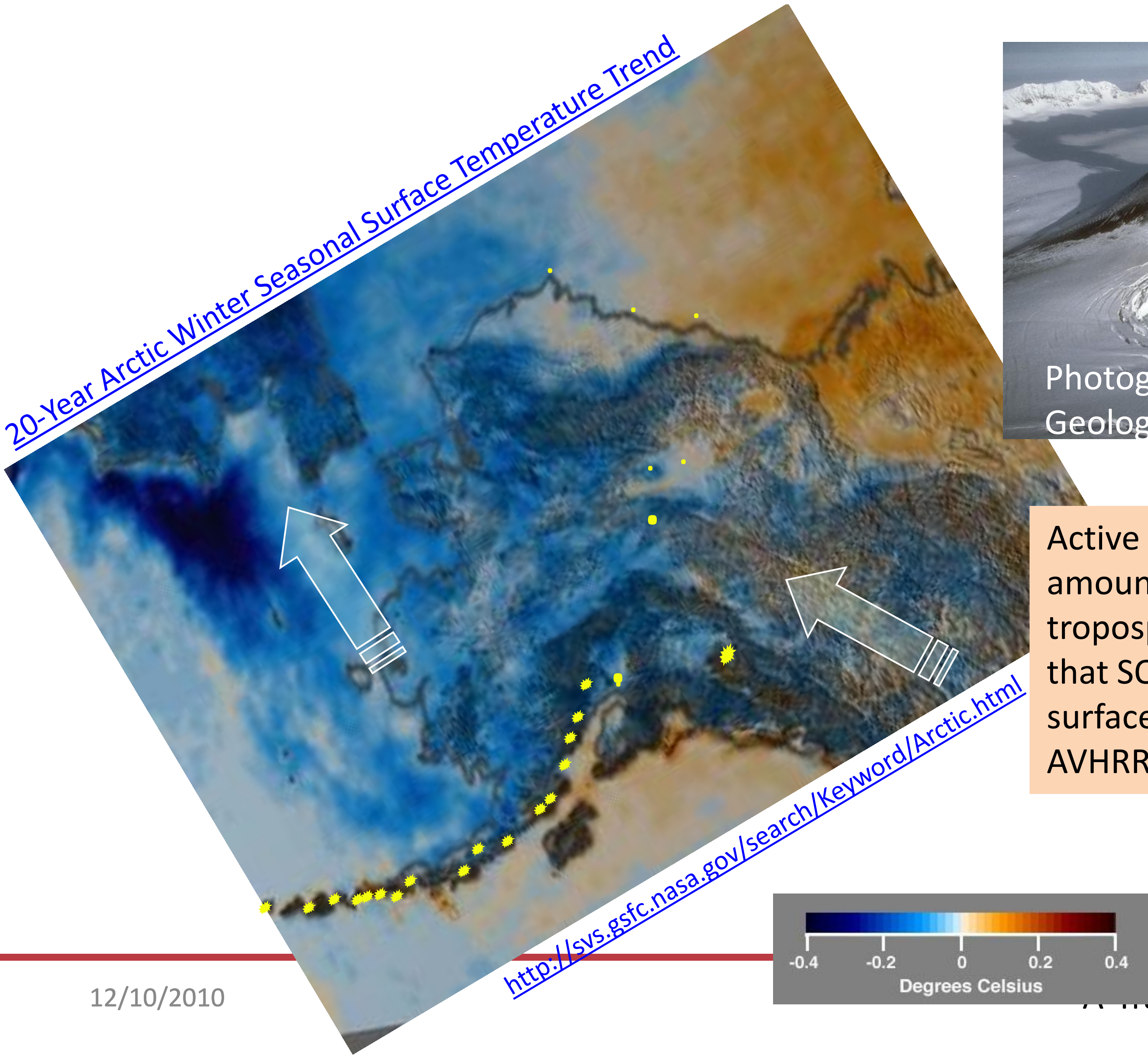

Large cloud increases in the in the fall provide significant source of warming (trapping IR) and an additional an extended in time feedback on ocean warming

The key strength of this analysis is that consistent relationships between cloud, sea ice, and atmospheric circulation patterns are found using four independent satellite data sets during a period that includes the two lowest sea ice extent years on record.

Kay & Gettleman, 2009

# Aerosol indirect effects : Sulphur Sources and AVHRR Arctic (Wintertime) Temperature Trend

[20-Year Arctic Winter Seasonal Surface Temperature Trend](http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html)




http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html

Photograph by M.E. Yount, U.S. Geological Survey, January 23, 1984.

Active Aleutian volcanoes emit large amount of sulphur in the lower troposphere. This is a strong indication that $SO_2$ – $SO_4$ sources are affecting surface temperatures trends shown in AVHRR.

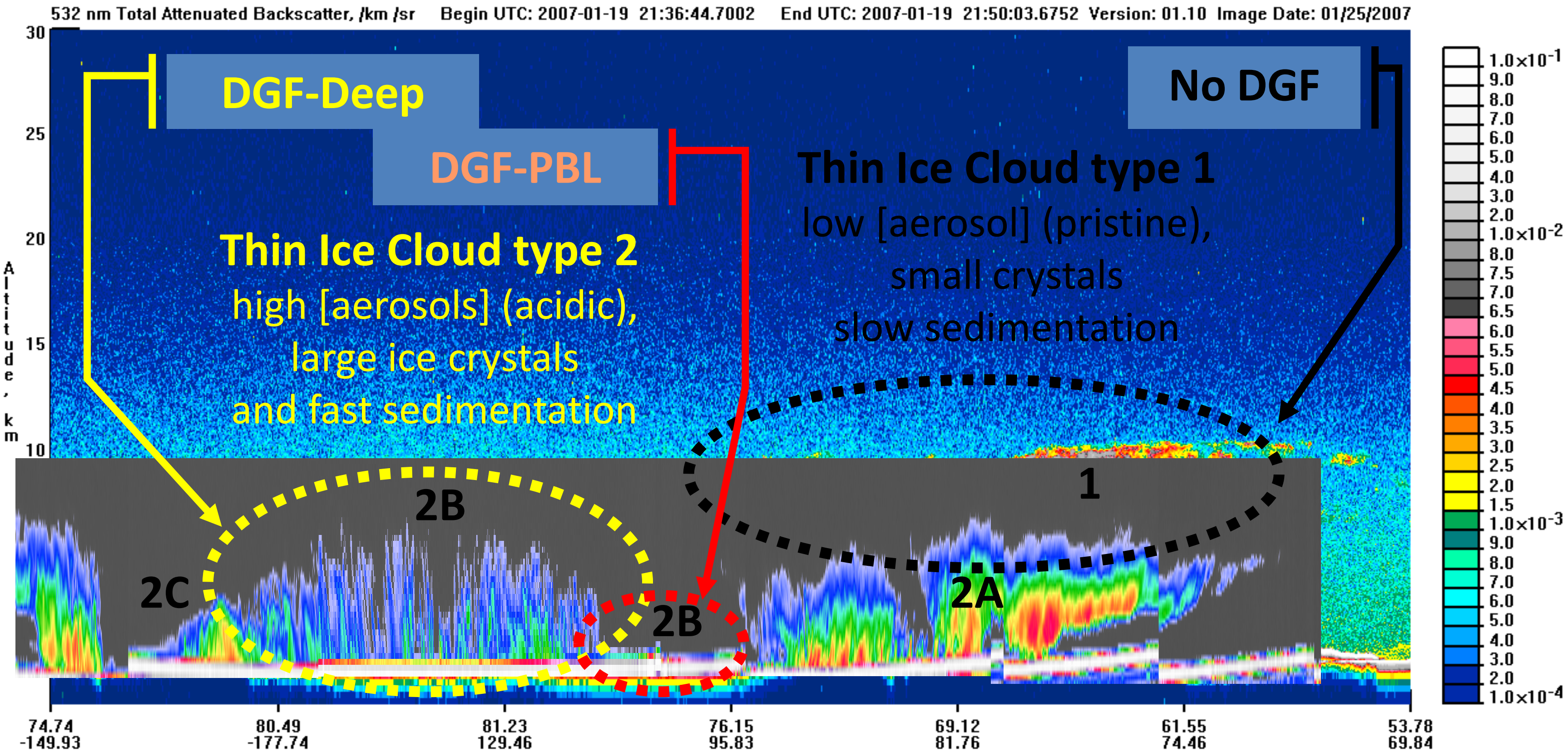
Blanchet et al., 2010

http://nationalatlas.gov/dynamic/dyn_vol-ak.html

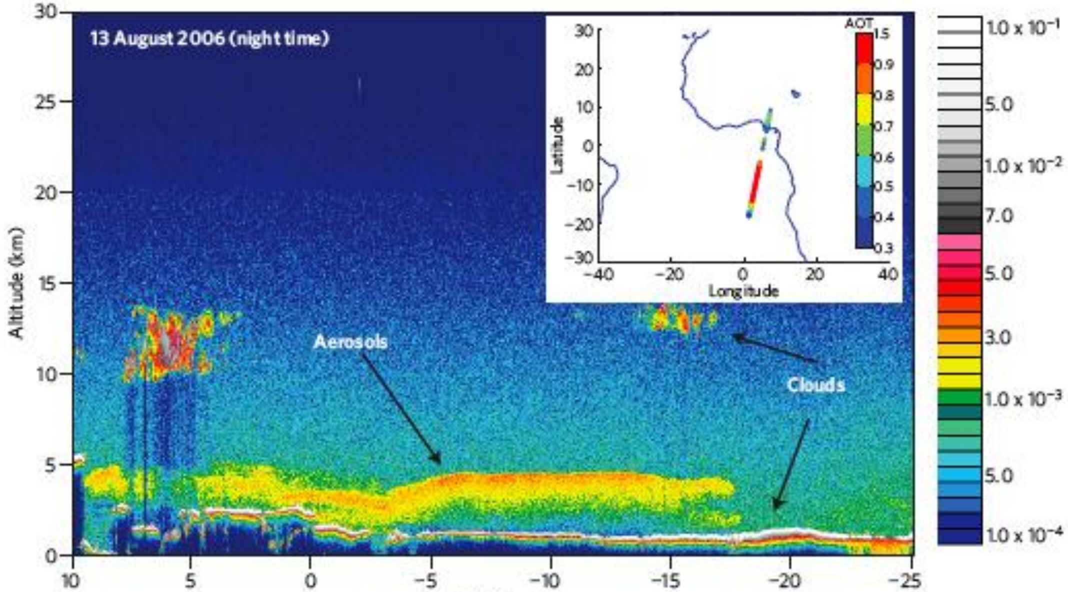
# Discovery of a new type of cloud

January 19, 2007

Radar – Lidar DGF Signature

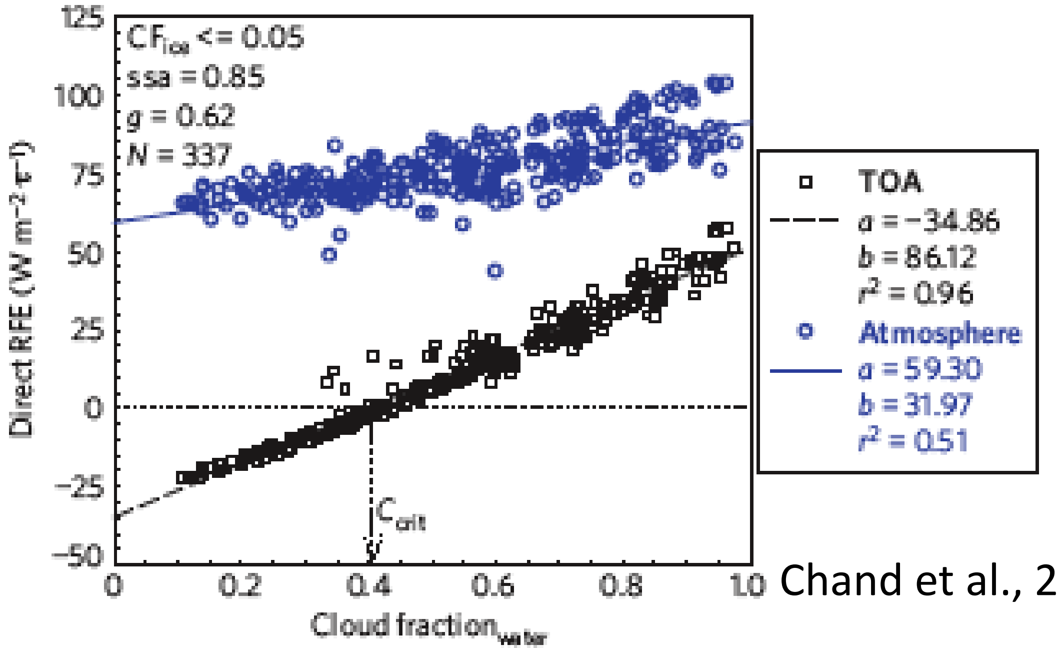


# Direct forcing by aerosol


PRIORITY RECOMMENDATIONS:

- ❖ Test and improve the ability of climate models to reproduce the observed vertical structure of forcing for a variety of locations and forcing conditions.
- ❖ Undertake research to characterize the dependence of climate response on the vertical structure of radiative forcing.
- ❖ Report global mean radiative forcing at *both* the surface and the top of the atmosphere in climate change assessments.



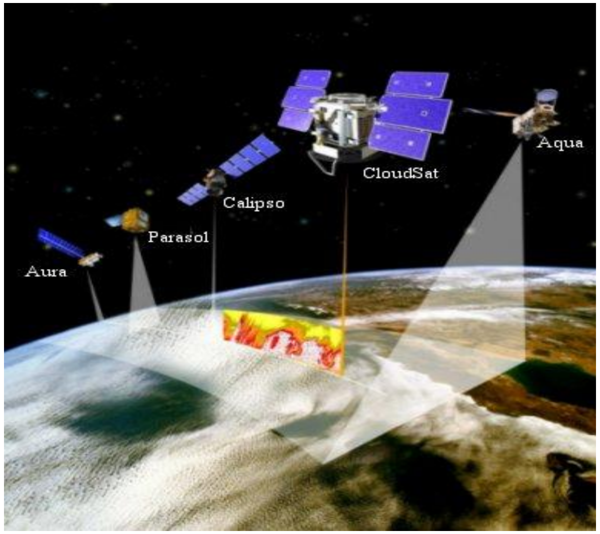

Chand et al., 2009

**Why relevant – and what the A-Train brings**: - Aerosol forcing is a key uncertainty in the prediction of climate change. The sign and magnitude of this forcing depends on the type of underlying surface below the aerosol. There are large differences in the aerosol forcing used in climate models particularly in regions of clouds, varying from -1 to +2 $Wm^{-2}$ in the region of this study. Aerosol forcing in these regions have been poorly constrained by traditional data sources that are restricted to identifying aerosols only in clear-sky situations.

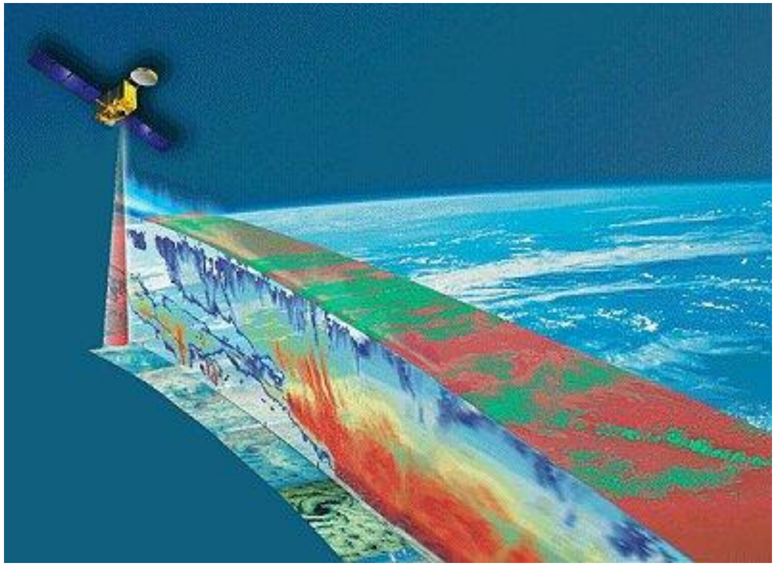
Summary: The A-Train is jewel in the EO crown providing unprecedented information about the Earth system and an ability to contribute to addressing the key model projection uncertainties (aerosol forcing and cloud feedbacks)

A-Train data has exposed major issues wrt the planet's energy balance, given a deeper and more integrated view of aerosol indirect effects, provides a rare look at planetary water cycle processes and has introduced entirely new ways of measuring ocean winds and aerosol.

The atmospheric profile data of the A-Train has demonstrated its vital importance to climate research and is a key measurement for monitoring cloud and aerosol effects on climate– as such this is an emerging an essential climate measurement that began with the A-Train and is to be continued with EarthCare and requires continuation beyond.




A-Train



EarthCARE 2014-2018/9

# Anticipated A-Train highlights

| Sensor data used | What is provided | Why useful | Interesting tidbits |
|---|---|---|---|
| CloudSat & CALIPSO | Vertical profiles of cloud occurrence, new definitions of high thin cloud, cloud base, cloud layering, baseline for cloud detection | This vertical structure is required for many weather and climate related analysis | Multiple layering is prevalent in tropics (60%), total cloud cover ~76% |
| MLS, CloudSat | Ice water content and path comparison | A weak link of models – agreement between these two data sets confirms validity of products | Good agreement - |
| AIRS, MODIS Cloudsat & CALIPSO | Cloud information from different sensors can be verified | Can calibrate other sensor data, like cloud top heights – useful for other applications like cloud track winds | Cloud top heights are very different between passive and active |
| AMSR-E & CloudSat | Evaluation or precip from both sensors | Provides a focus to extra-tropics where largest differences occur | AMSR-E precip occurrence is ~ 2X less than CloudSat |
| AMSR-E , MODIS & CloudSat | Cloud liquid water path of raining/non-raining clouds | Tests two related products – defines limitation of both | Validity of AMSR-E is much more restricted than MODS |
| AMSR-E CERES, ,Cloudsat, MODIS | More integrated view of aerosol indirect effects on observed cloud albedos | Large uncertainties in AIE – one of the principle tools that constrain models sensitivities to 'region of comfort' | AIE are inferred to be small composed of many unaccounted for cancelling effects |

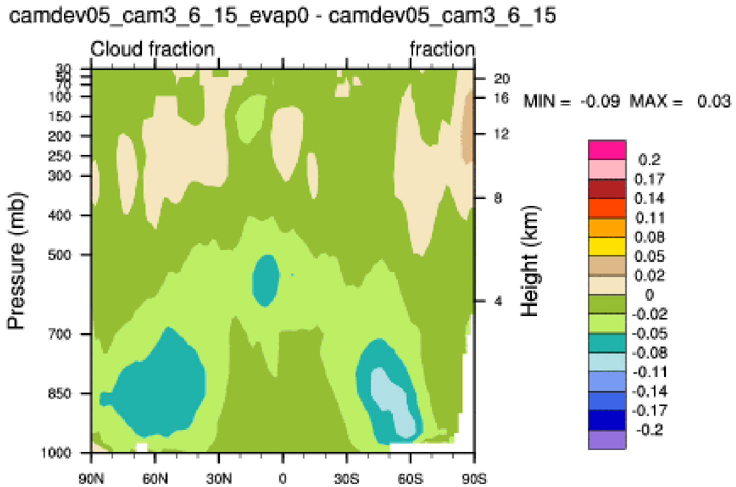
# A-Train Serendipity

| Sensor data used | What is provided | Why useful | Interesting tidbits |
|---|---|---|---|
| MODIS IR, CloudSat, CALIPSO | Convective buoyancy, entrainment | Provides unique, global information that will revolutionize model convection parameterization | Verified hot tower hypothesis – 0.02% of tropics contain undilute convective cores |
| AMSR-E, CALIPSO | Surface wind from lidar surface reflection | CALIPSO surface wind sees in between clouds and is less contaminated by cloud effects | 1m/s rms, near zero bias compared to AMSR-E |
| Cloudsat & CALIPSO | Aerosol optical depth via PIA –radar surface reflectivity is used to define lidar surface reflection | AOD much less sensitive to aerosol model assumptions that plague all other methods | |

# A-Train Serendipity

| Sensor/ data | What is provided | Why useful | Interesting tidbits |
|---|---|---|---|
| MODIS vis, nir, CloudSat, | Correlation between radar reflectivity and MODIS particle size | Provides unique identification of the transition from cloud to rain and time scale of rain formation | Time scale is much longer in nature than is assumed in models |
| OMI , CloudSat, | Inferred cloud top heights fro UV scattering matched to cloud profiles | Impacts ozone estimation above clouds | Considerable UV multiple scattering makes OMI cloud tops appear many kms low |
| CloudSat & MODIS | A confirmation of MODIS particle size and its relation to precipitation | Passive measures particle size of low clouds can be used to characterize drizzle/precip occurrence. | Drizzle is so persistent in oceanic clouds that it measurably affects the mean particle size |
| ColudSat & CALIPSO | Identification of thin winter time ice clods and it precipitation | Explosive development of precipitation altered by aerosol affecting the rate of dehydration of polar clouds | A new type of cloud – one of large particles water is primarily in reciptation |

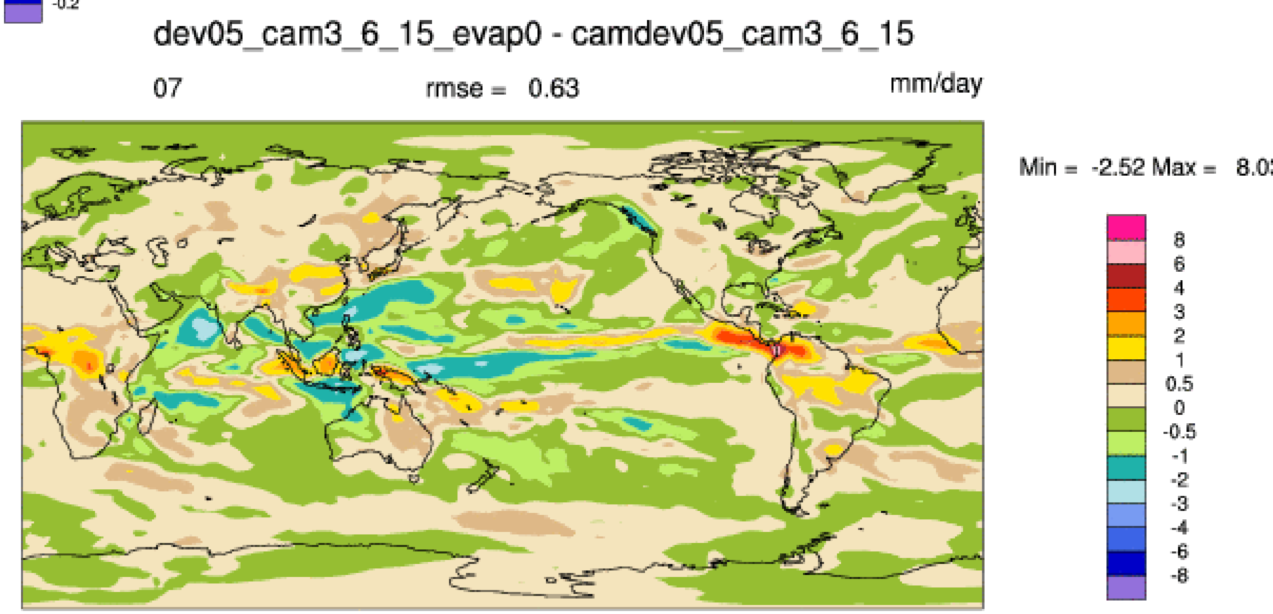
# Why light rain?




Cloud amount
Model simulation
No evap – evap
10% increases in mid lat clouds

Precipitation change
No evap-evap
10% decrease in tropical precipitation

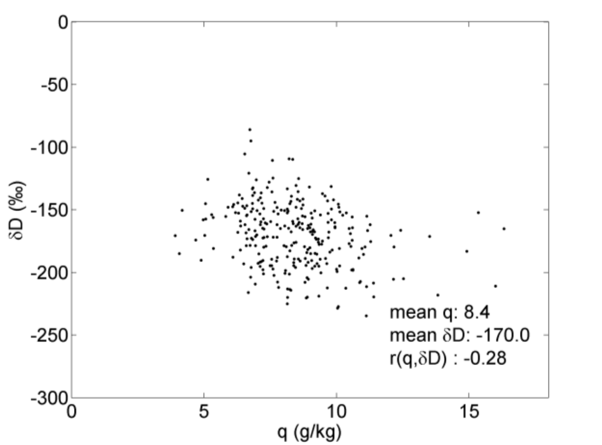
1) Light rain is more strongly evaporated as it falls – this is a significant source of atmospheric moisture that significantly affects precipitation, cloud cover an the radiation balance
2) Probe the warm rain process and transition from cloud-to rain



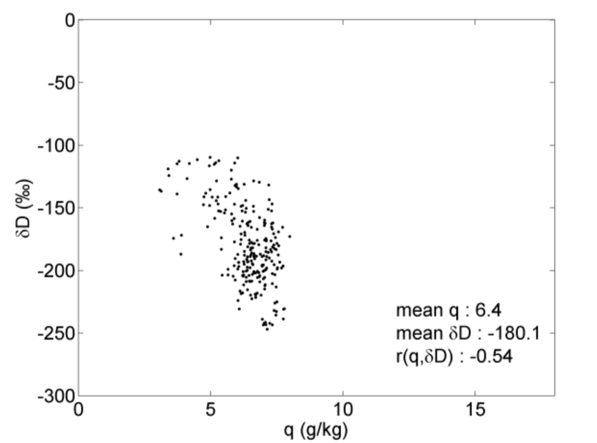
Problem: Global climate models show that moisture recycling due to evaporation of rainfall should be an important process controlling tropical humidity; however this process is difficult to measure directly.

Measurements of the isotopic composition of water vapor place a direct constraint on this moistening process because the isotopic composition of water vapor depends on the moisture source and changes in phase between vapor and precipitation.

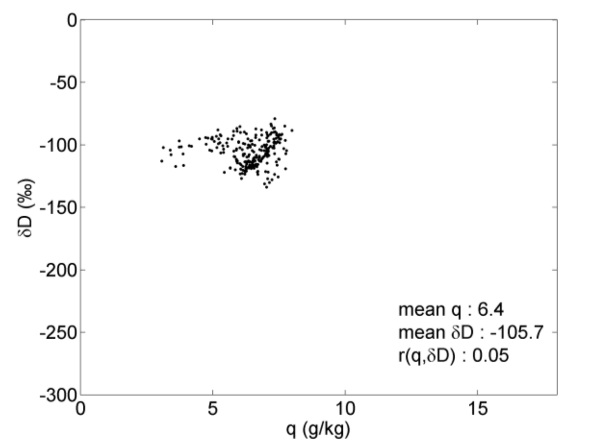
Using the new isotope measurements from the Aura TES instrument, we identified this isotopic signature in the form of an anti-correlation between the ratio of HDO to $H_2O$ (denoted δD) versus $H_2O$ (q) in regions of strong tropical convection such as the Asian Monsoon. Using detailed experiments with the GISS climate model, we were then able to attribute this signature to moisture recycling exclusively.  A future analysis will account for the coarse vertical resolution of the TES data which should improve the comparison.




Over the Asian Monsoon region, the TES data show that increasing humidity (q) corresponds to isotopically lighter water vapor (δD).




A similar anti-correlation appears in the GISS climate model when isotopic processes during moisture recycling are enabled.



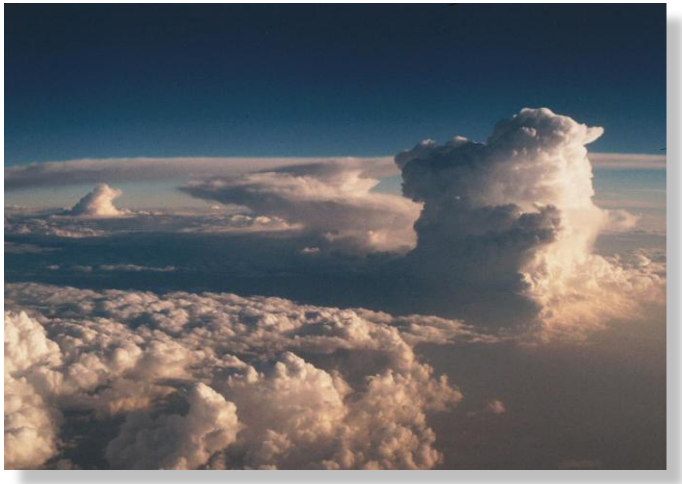

Without these processes, the anti-correlation is absent.



R. Fields, Jones, and Brown, JGR, In Press 2010

# The two sources of uncertainty:

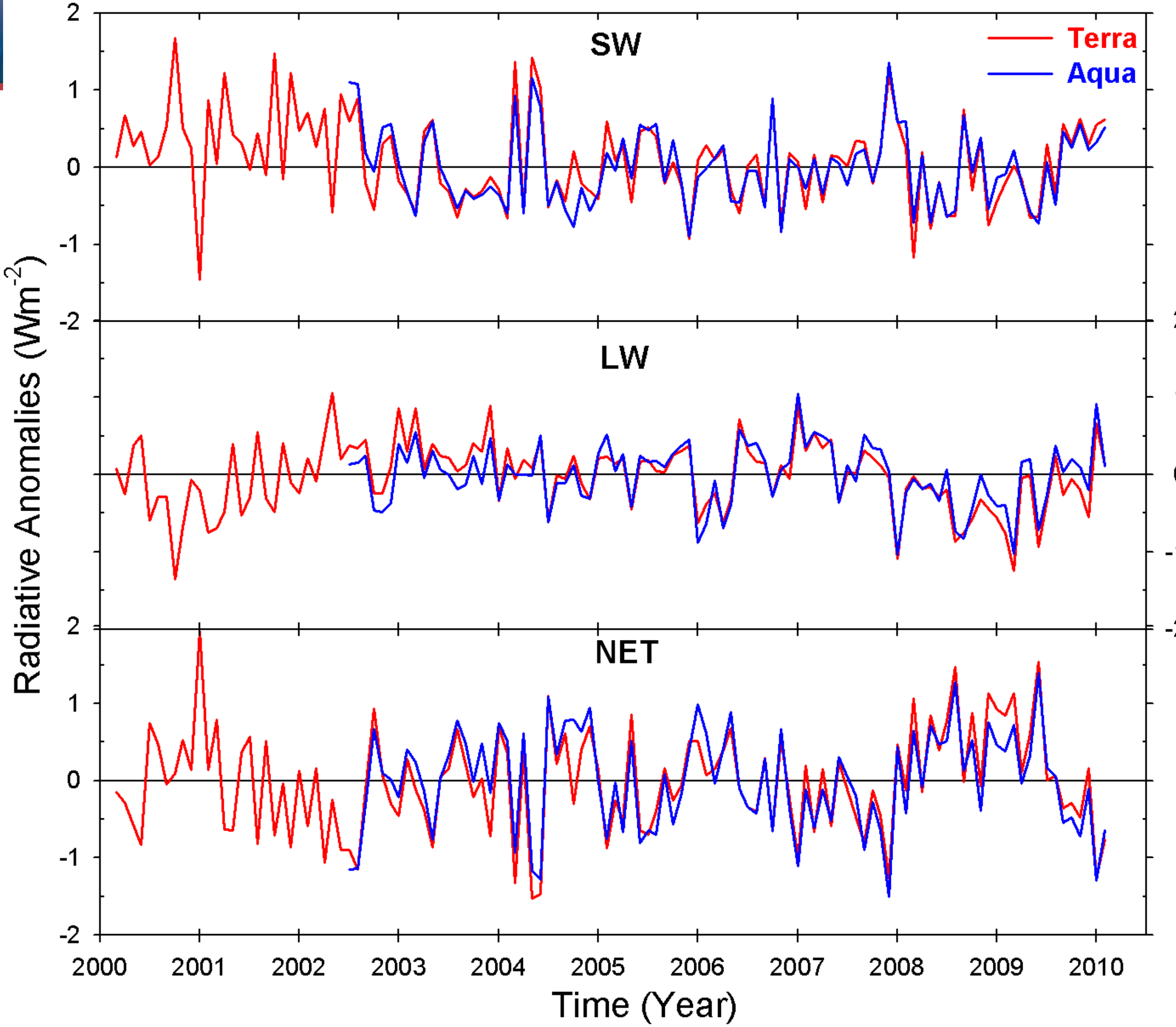
The total direct aerosol radiative forcing (RF) derived from models and inferred from observations ….*a medium-low level of scientific understanding. The (indirect) RF* ….a *low level of scientific* understanding.



Substantial progress has been made in understanding the inter-model differences in equilibrium climate sensitivity. Cloud feedbacks have been confirmed as a primary source of these differences, with low clouds making the largest contribution.

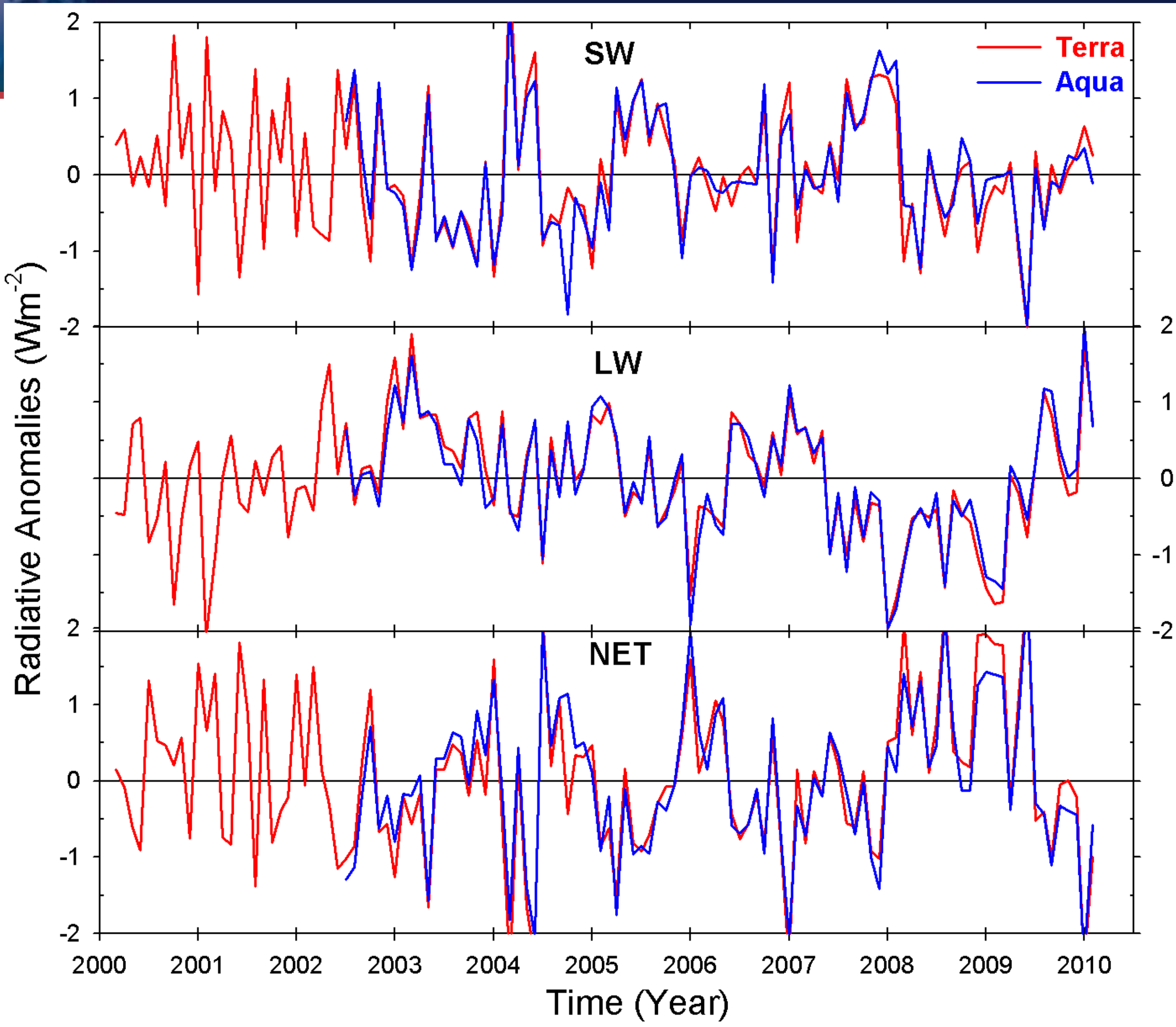
AR4

# Global CERES Top-of-Atmosphere Radiation Anomalies




**CERES is providing the first decadal global climate data record of the Earth's Radiation Budget at climate accuracy from broadband instruments.**

# Tropical CERES Top-of-Atmosphere Radiation Anomalies



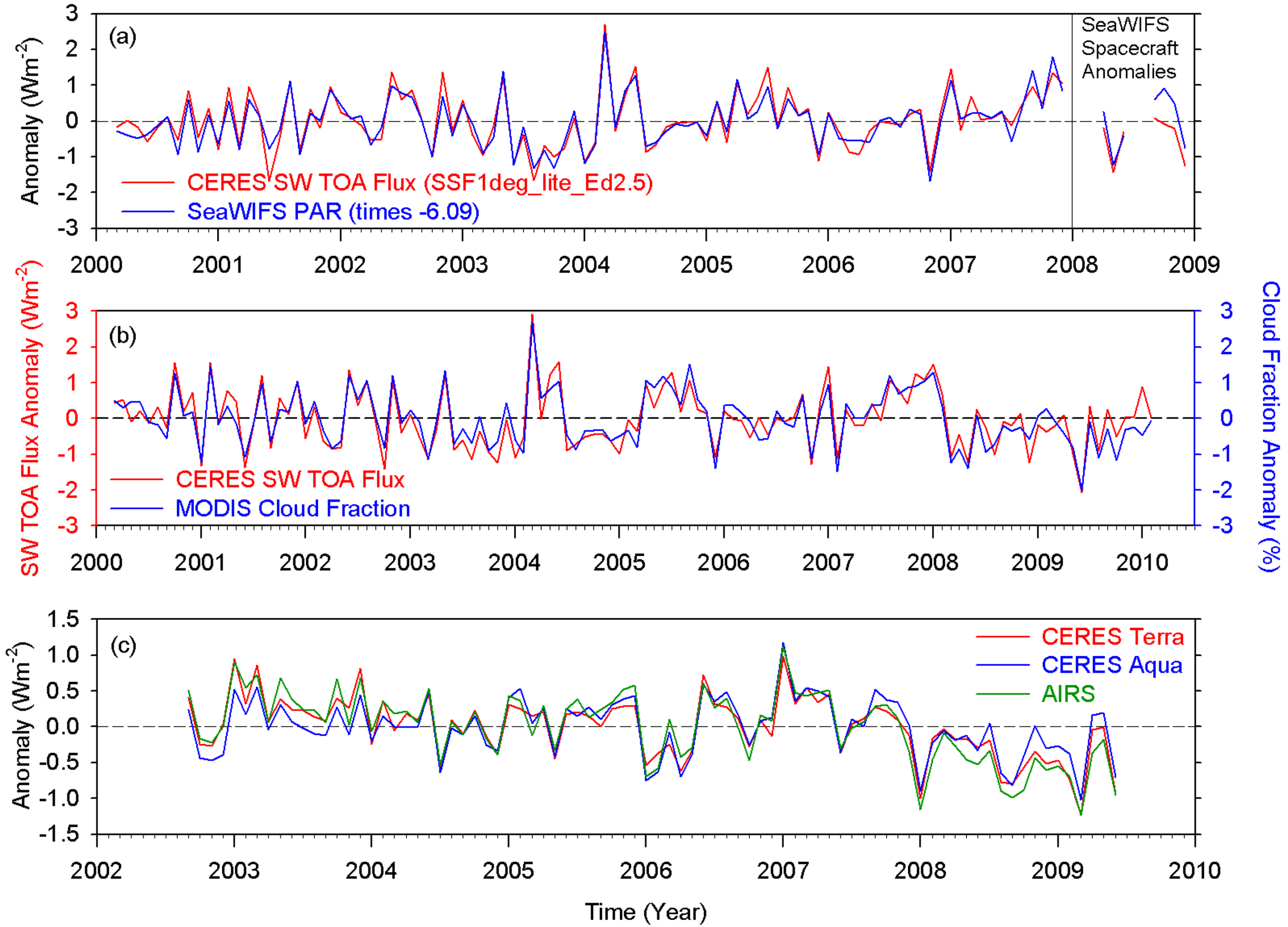
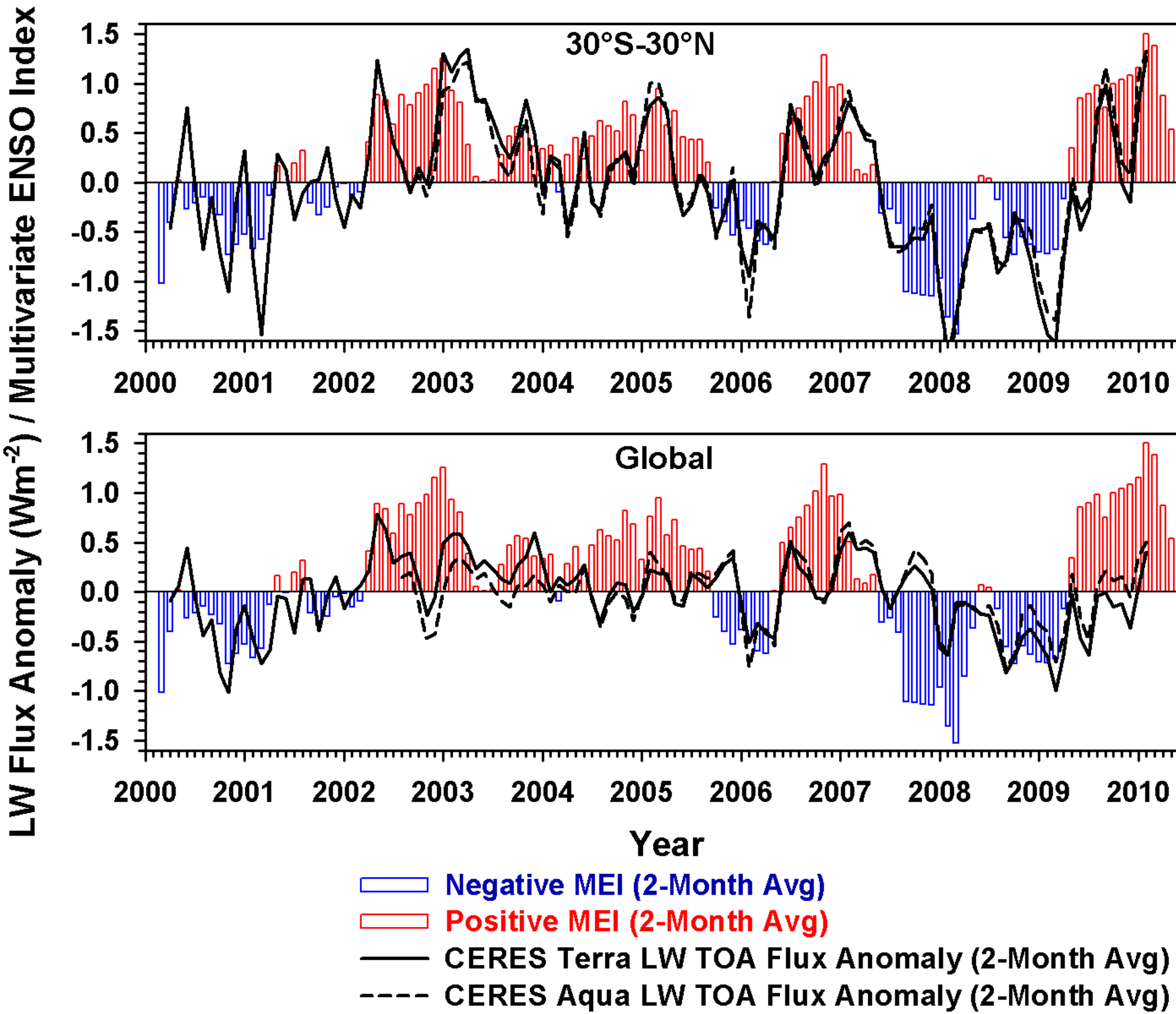


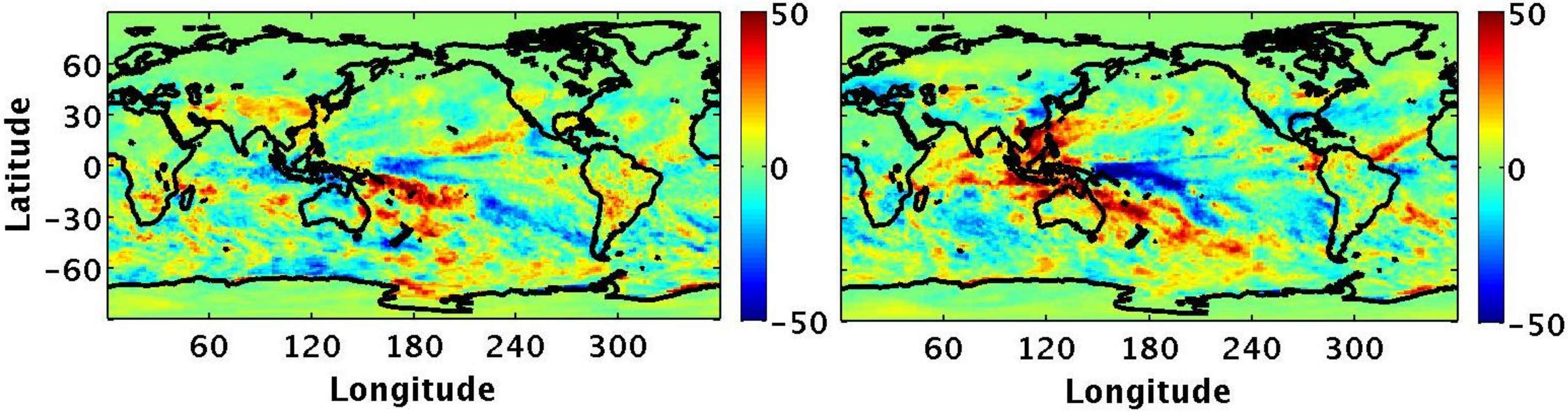

Figure 3 Monthly anomalies in (a) CERES Terra SW TOA flux from SSF1deg-lite_Ed2.5 and SeaWiFS PAR scaled by a factor of -6.09 (corresponding to the slope of the regression line fit relating CERES SW TOA flux and SeaWiFS PAR anomalies) over ocean for 30°S–30°N from March 2000 to December 2009, (b) CERES Terra SW TOA flux and MODIS cloud fraction for 30°S–30°N between March 2000 and February 2010, and (c) global LW TOA flux from CERES Terra, CERES Aqua and AIRS Aqua for September 2002–June 2009.



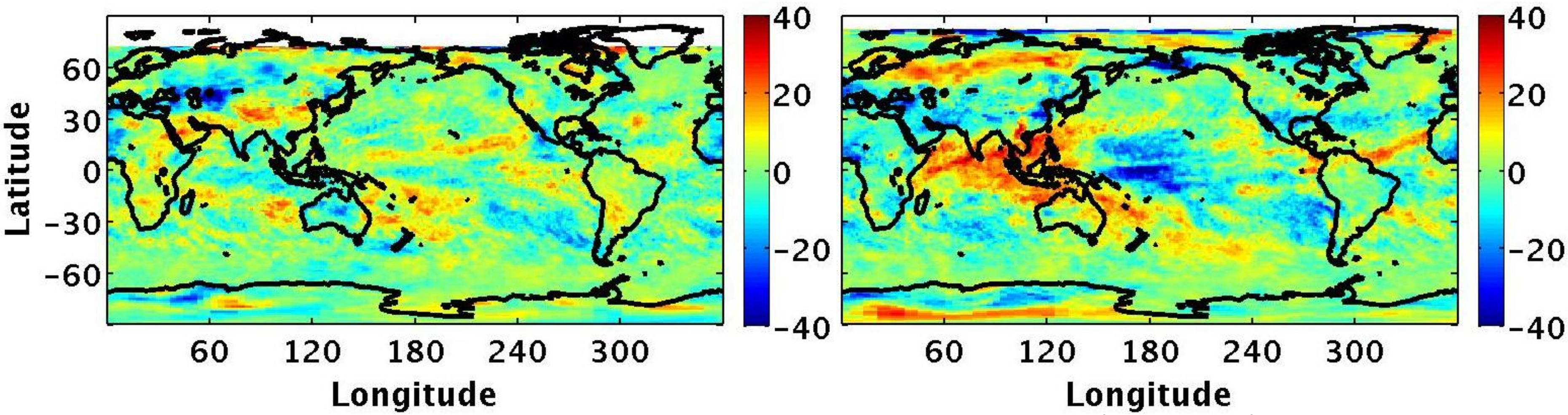
LW Flux Anomaly (Wm$^{-2}$) / Multivariate ENSO Index
30°S-30°N
Global
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Year
Negative MEI (2-Month Avg)
Positive MEI (2-Month Avg)
CERES Terra LW TOA Flux Anomaly (2-Month Avg)
CERES Aqua LW TOA Flux Anomaly (2-Month Avg)

# CERES SW TOA Flux and MODIS Cloud Fraction Anomalies

CERES SW TOA Flux Anomaly (Wm$^{-2}$)

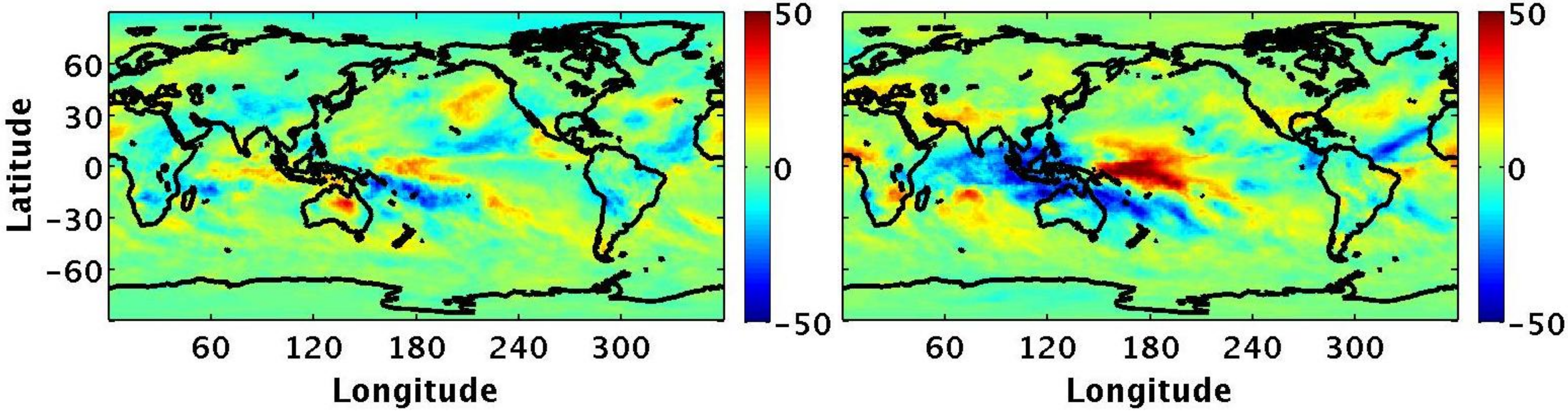



MODIS Cloud Fraction Anomaly (%)

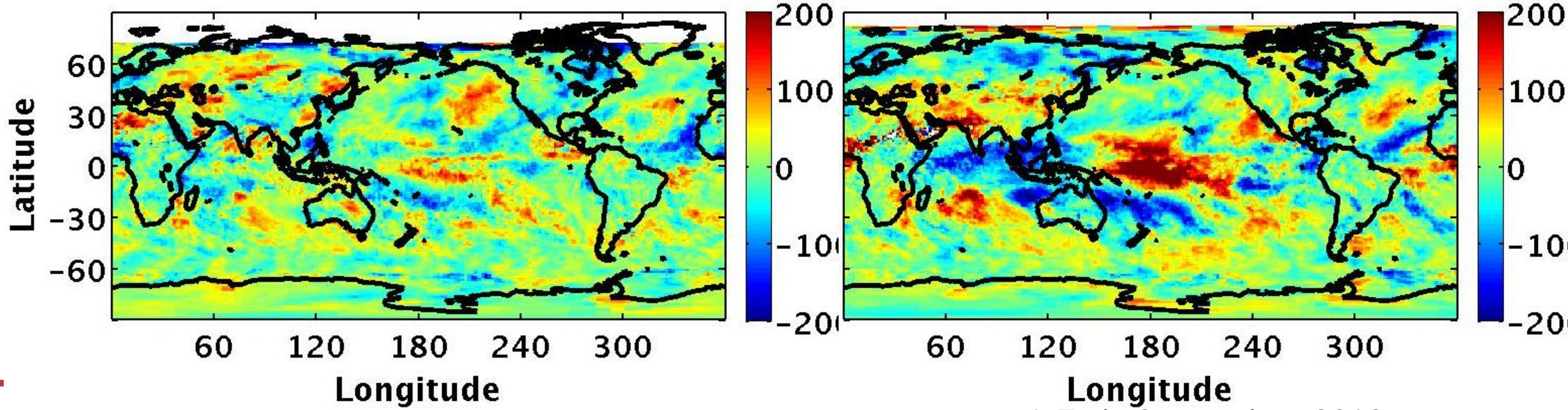


# CERES LW TOA Flux and MODIS Cloud Top Pressure Anomalies

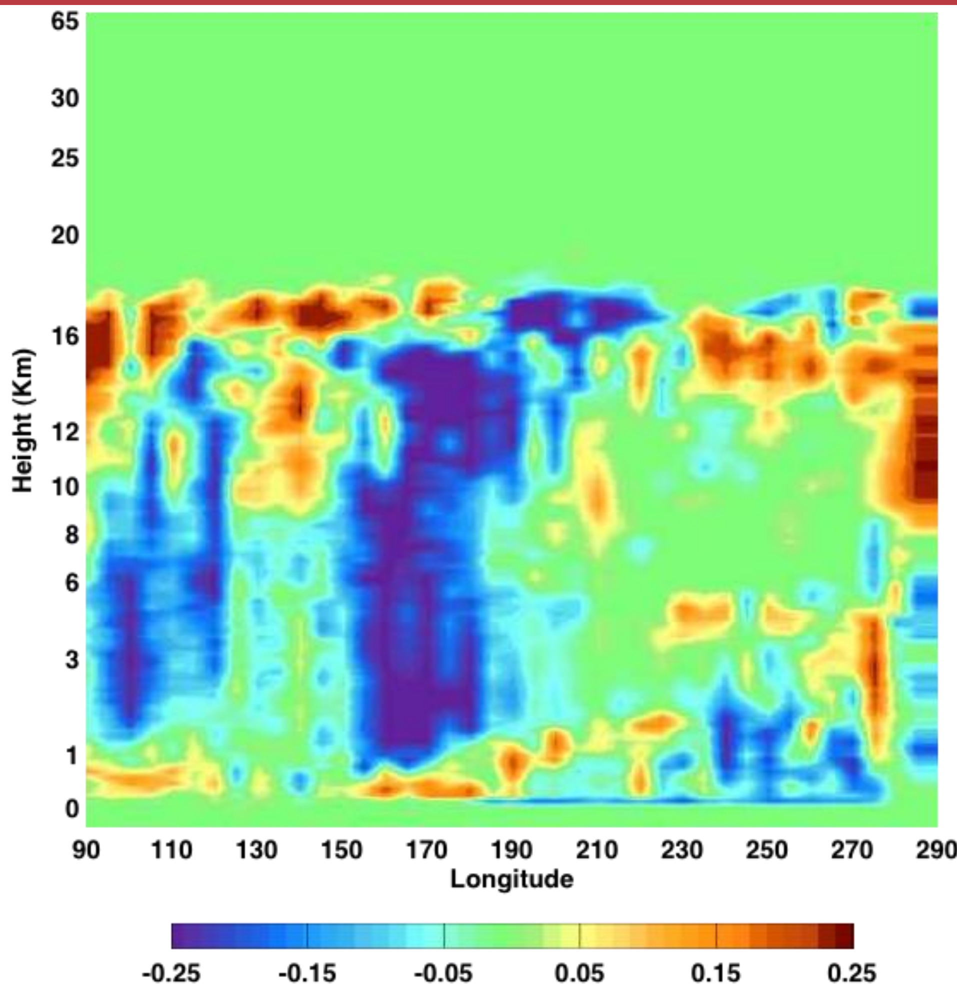
CERES LW TOA Flux Anomaly $(Wm^{-2})$



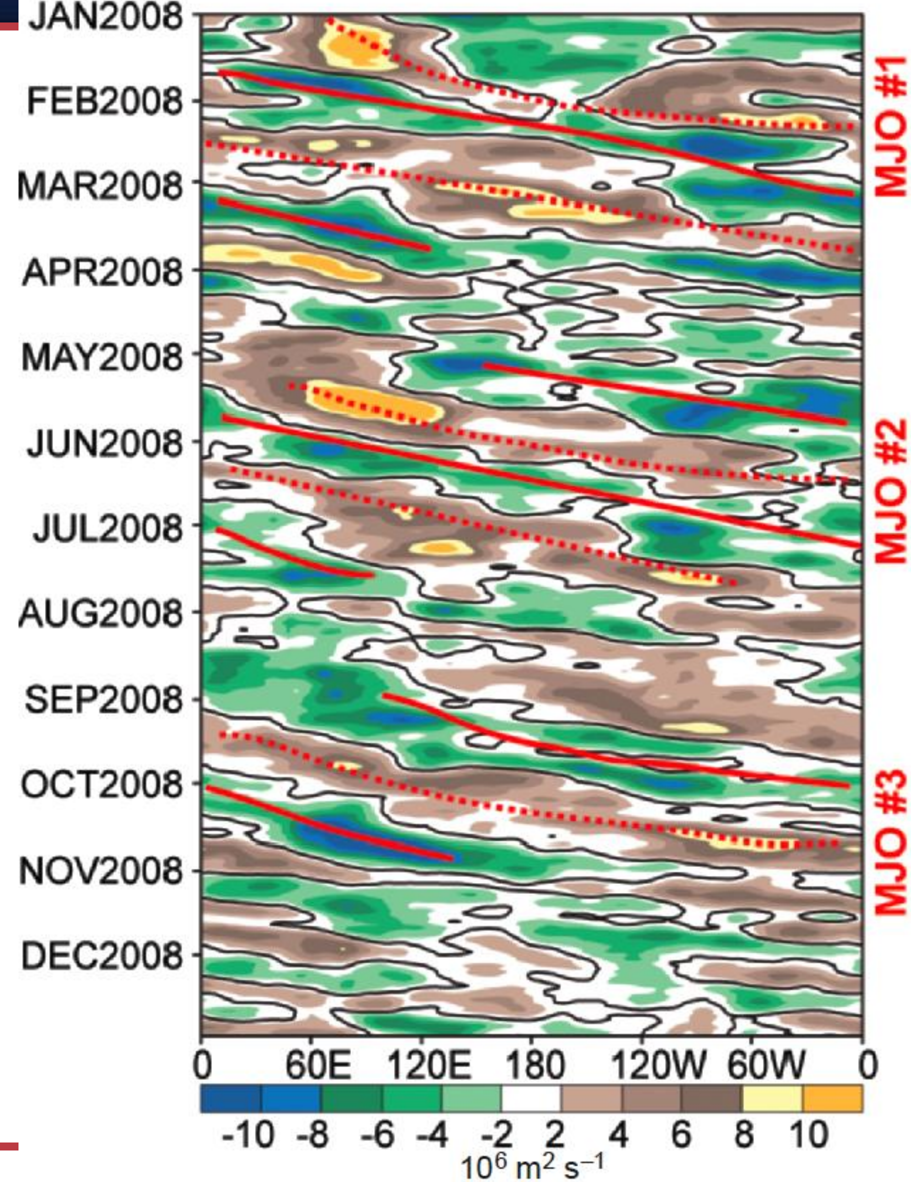

MODIS Cloud Top Pressure Anomaly (hPa)



## Cloud Frequency of Occurrence Difference Jan08 minus Jan07 (0S–2.5S)



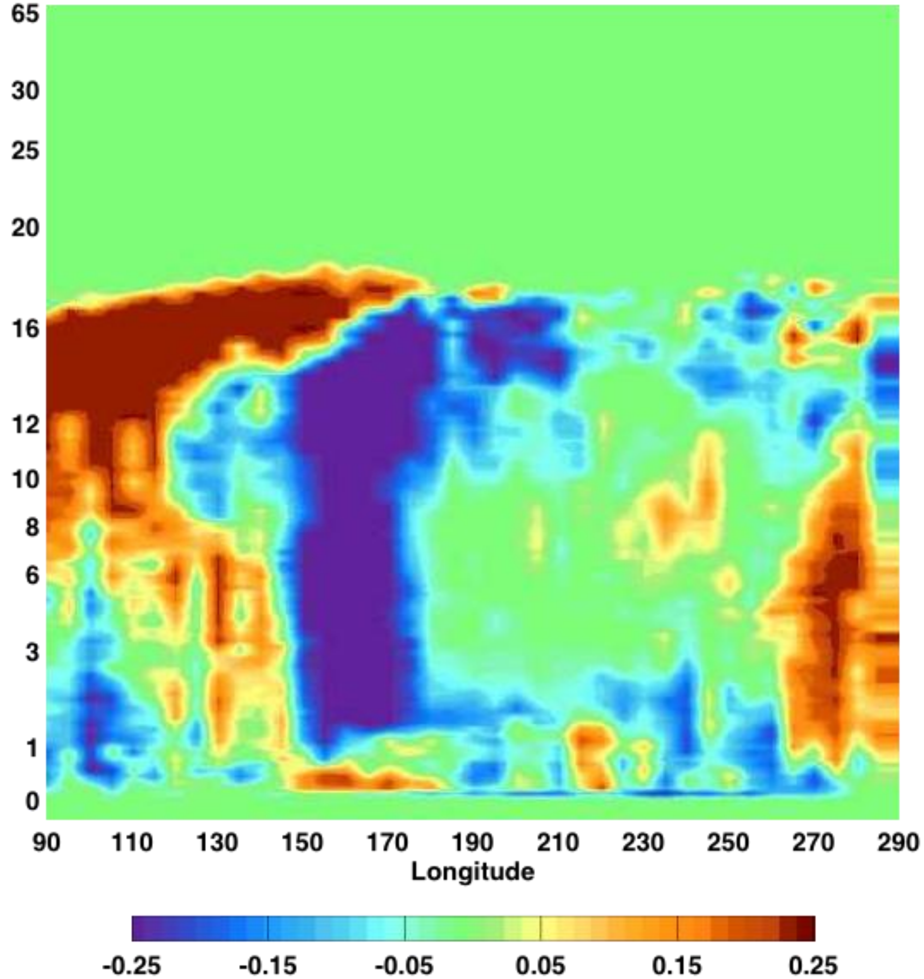

## Filtered 200-hPa Velocity Potential Anomaly (5S–5S)



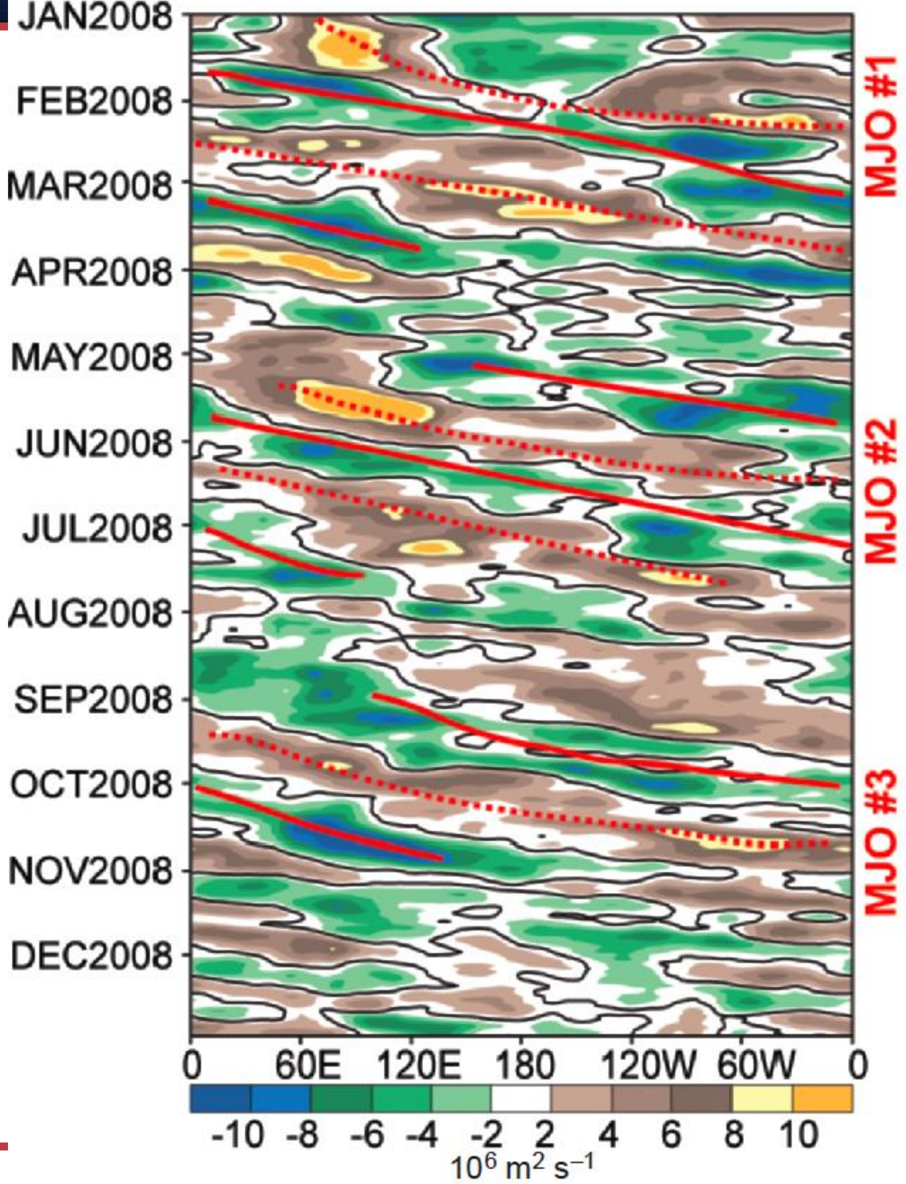



- MJO and La Nina convection out of phase: Negative phase of MJO masks La Nina Convection

## Cloud Frequency of Occurrence Difference Feb08 minus Feb07 (0S–2.5S)

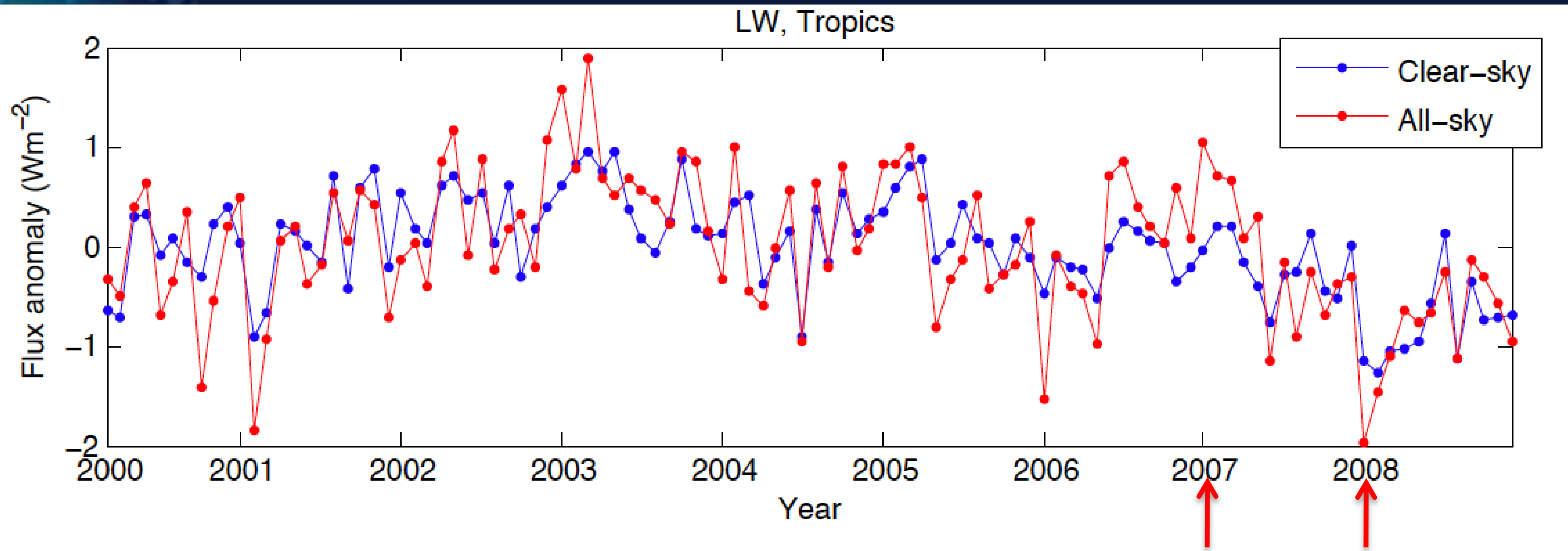



## Filtered 200-hPa Velocity Potential Anomaly (5S–5S)

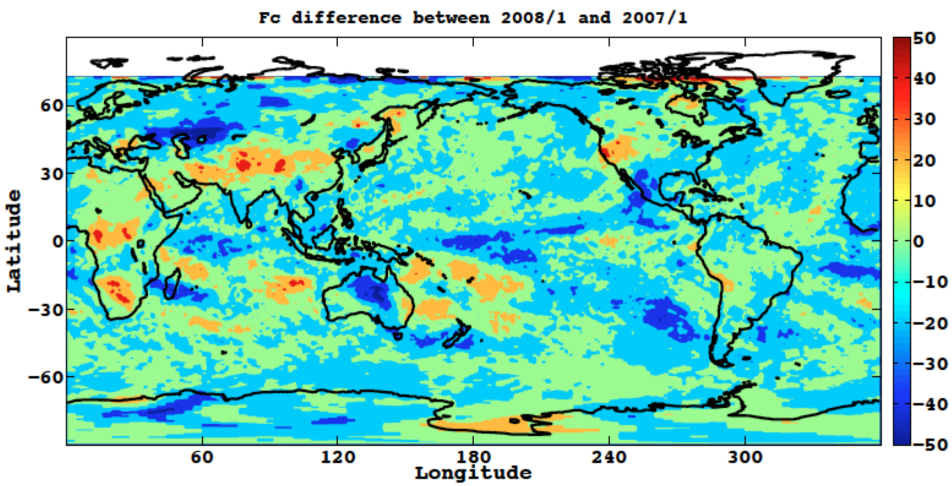



MJO and La Nina convection in phase

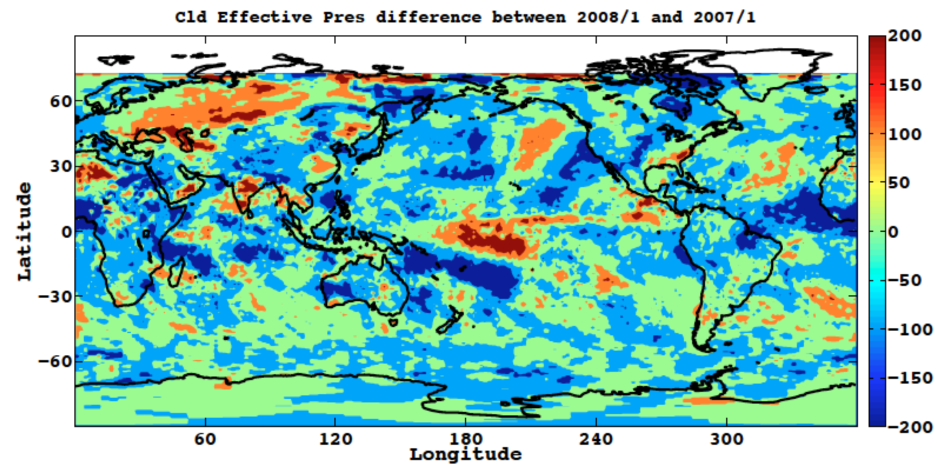
# LW TOA anomalies over tropics




Cloud fraction difference 200801 - 200701

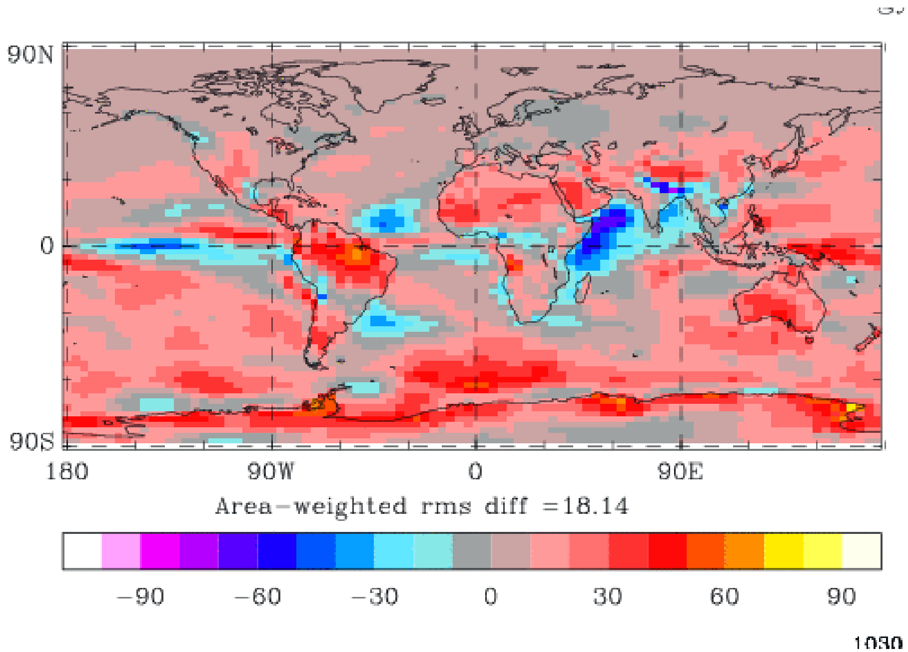


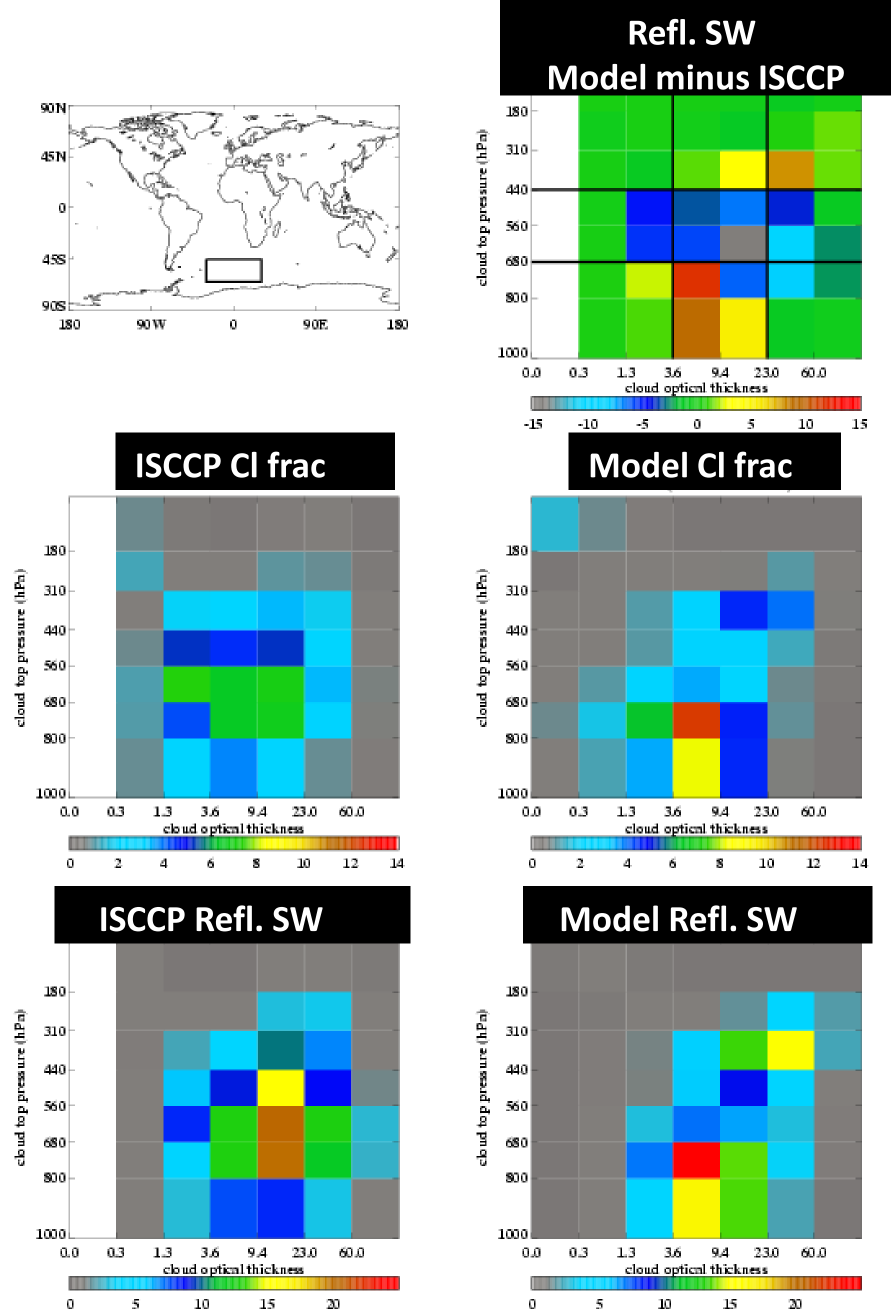

Cloud effective pressure 200801 - 200701



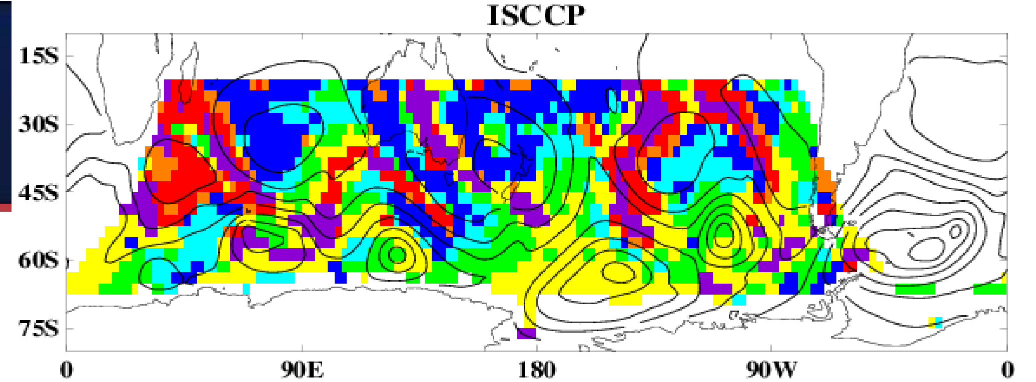
# Example analysis 1:
# Southern Ocean warm bias
# (MetUM)

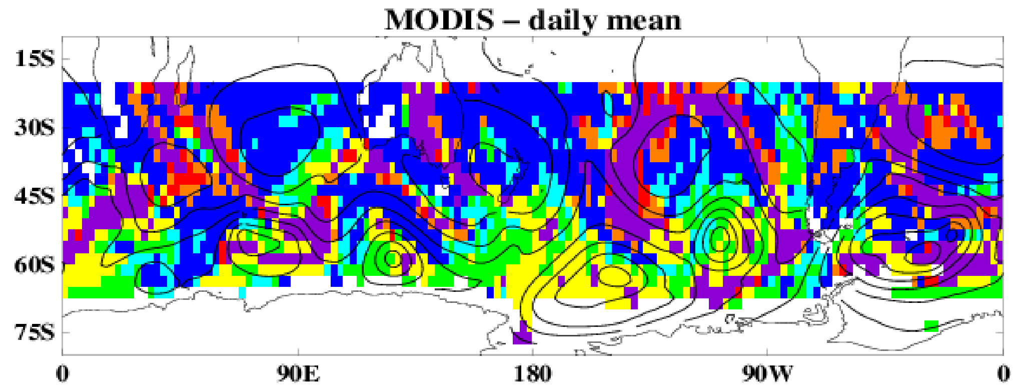
# Climate model

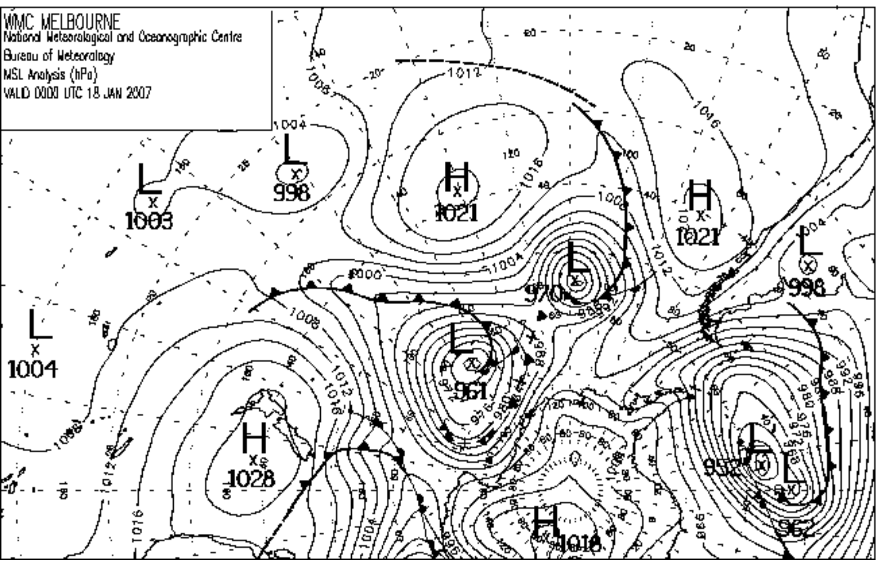


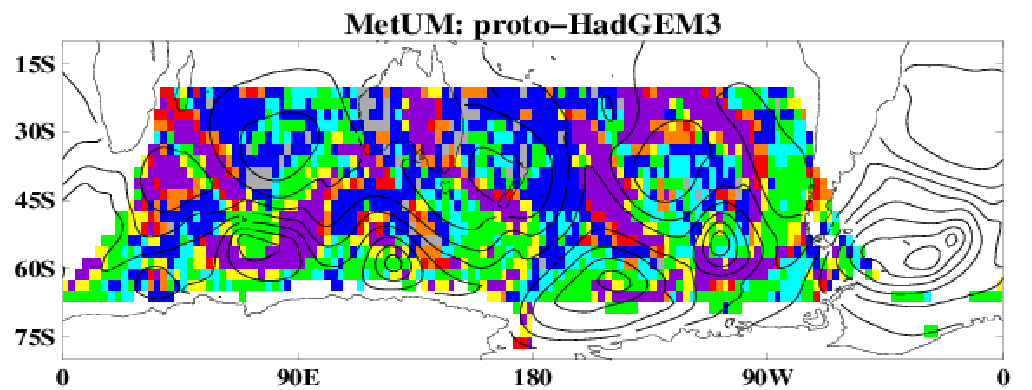



- Clear–sky
- Shallow Cu.
- Transition
- Stratocu.
- Mid–level
- Thin Cirrus
- Cirrus
- Frontal

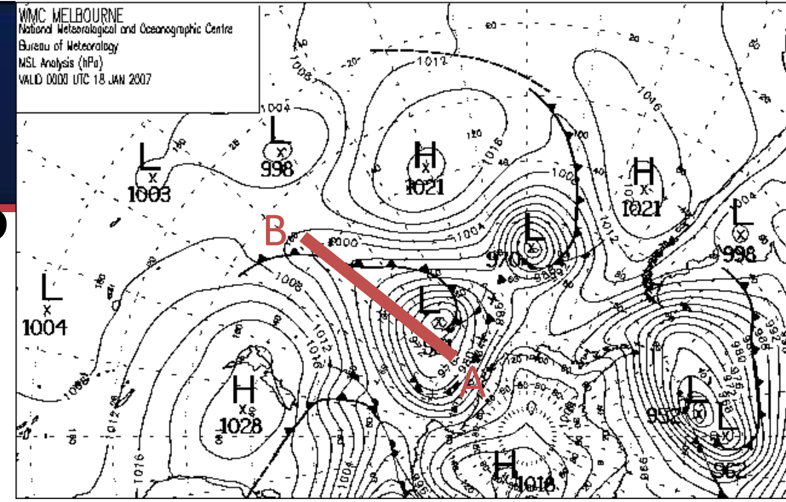


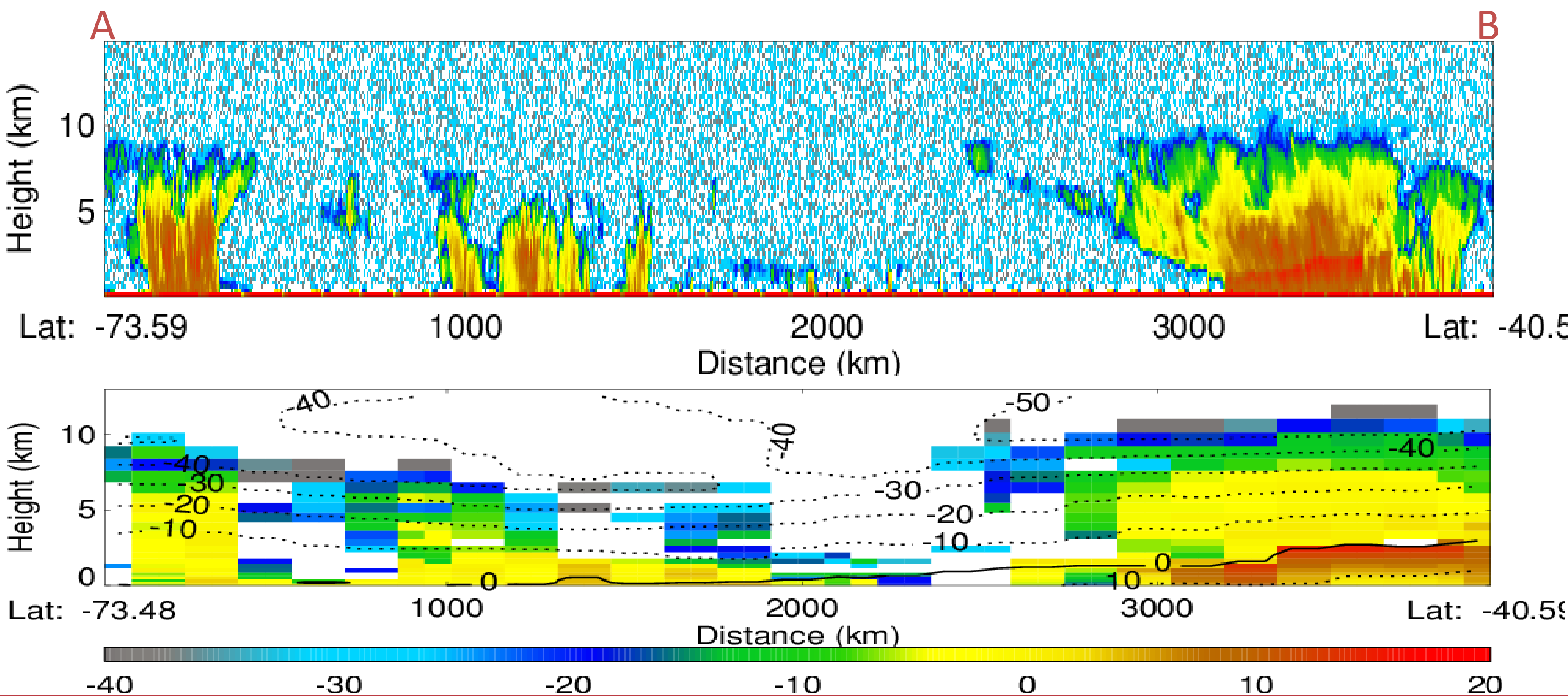



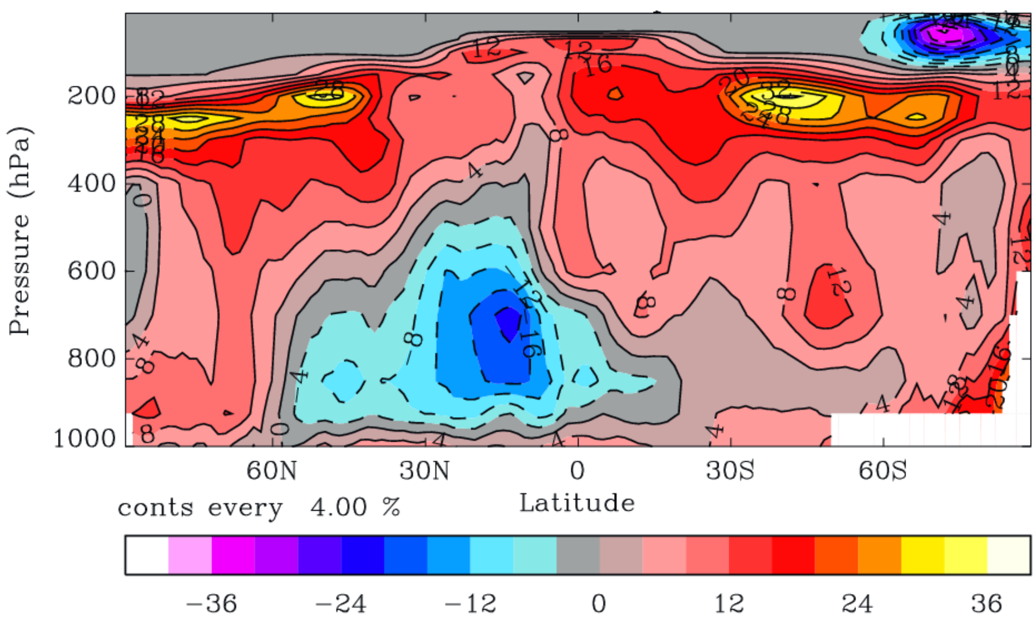
# Comparison with CloudSat using COSP

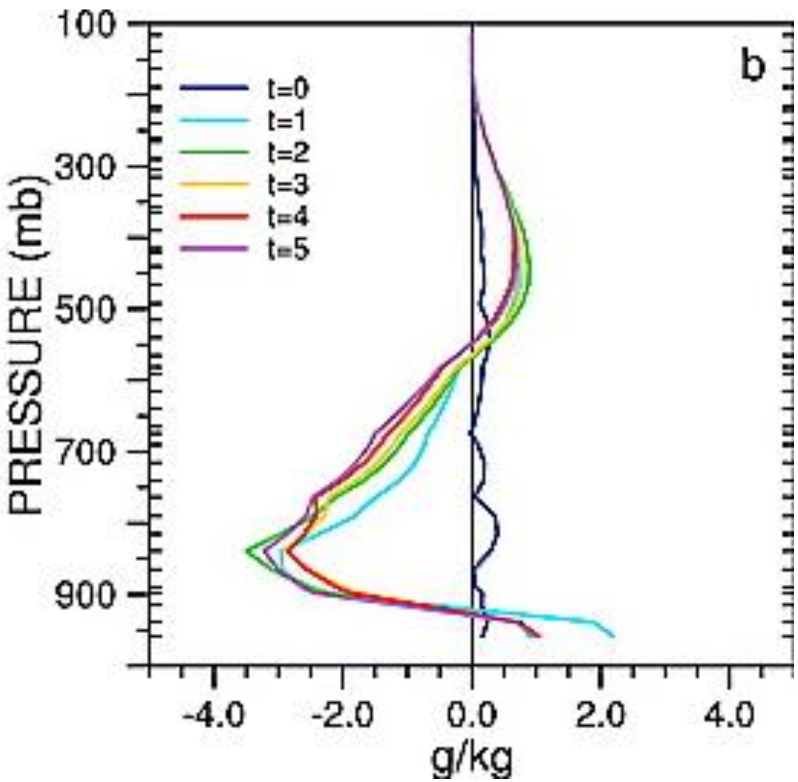


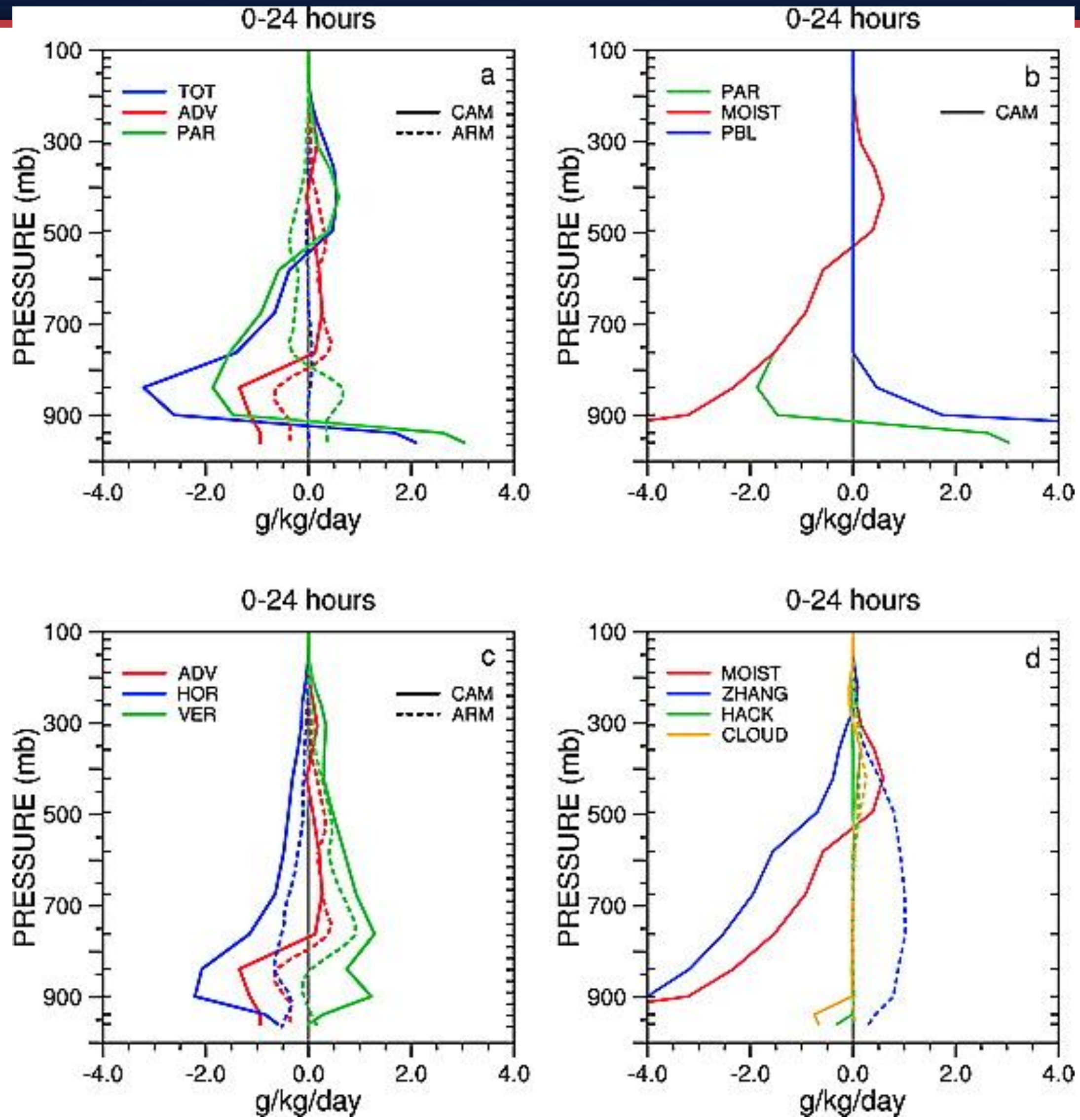
Example analysis 2:
Dry lower troposphere
(NCAR CAM)

# CAM humidity errors



# Breakdown of hindcast tendencies

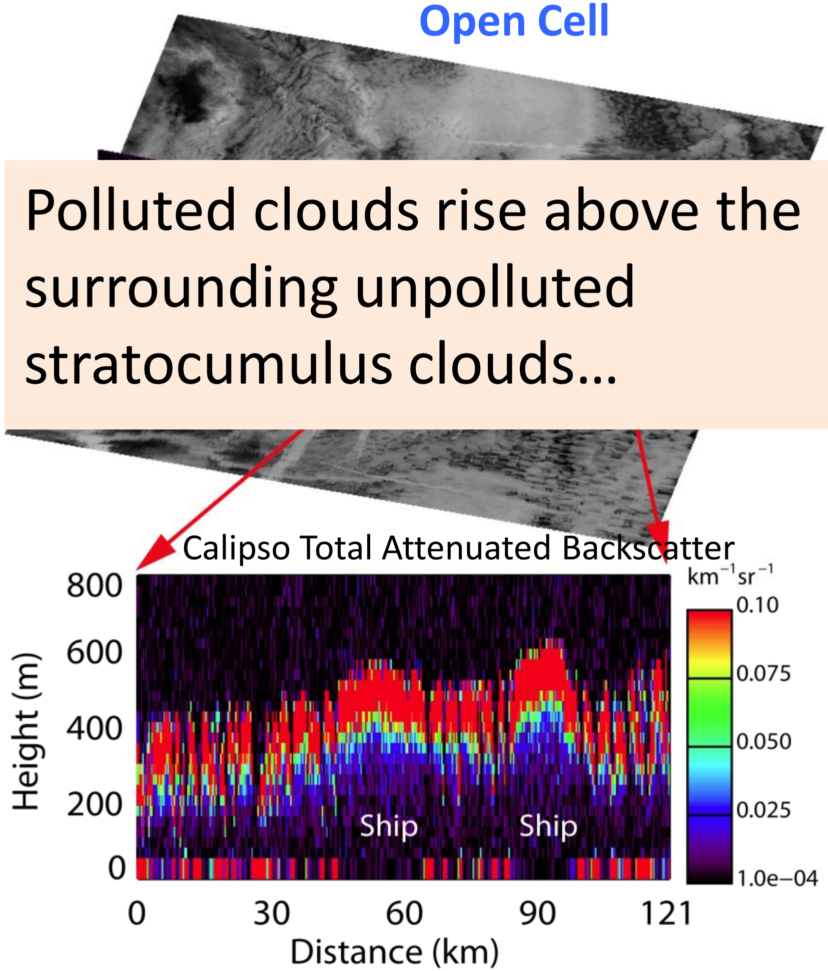


# 3a) Aerosol influences on warm clouds

8/8/2007 22:55 UTC

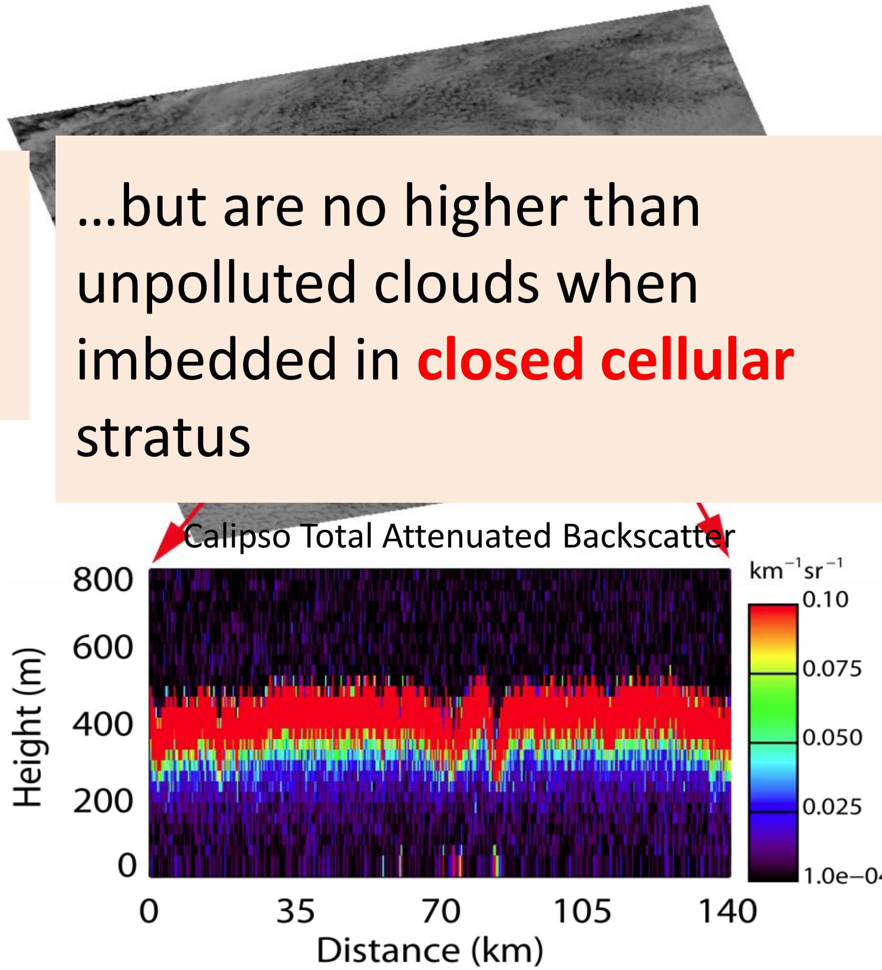
**Open Cell**

Polluted clouds rise above the surrounding unpolluted stratocumulus clouds…



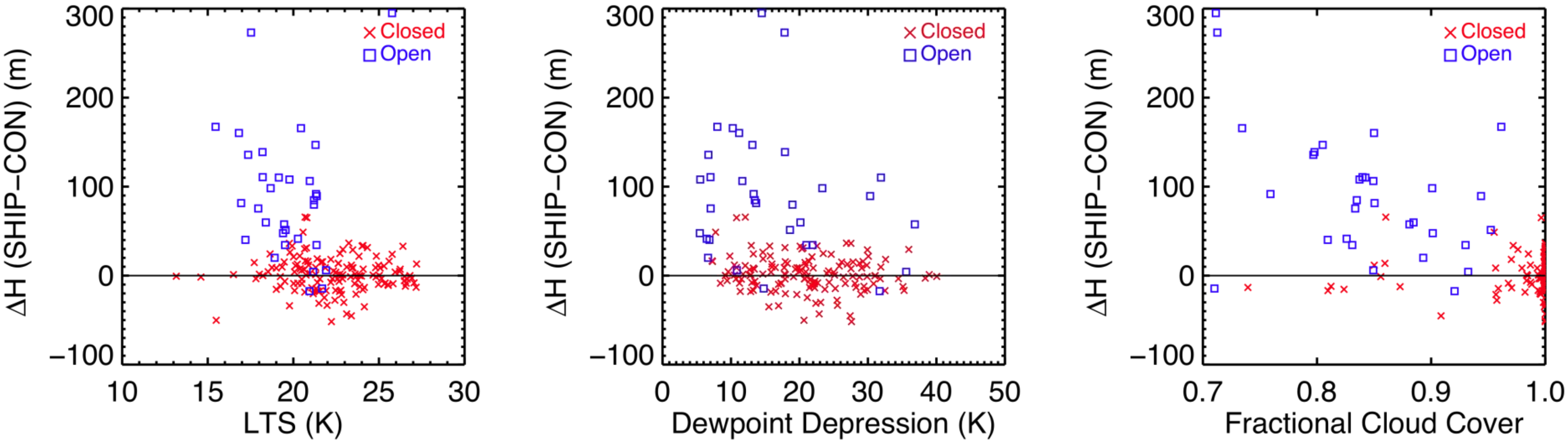

8/23/2007 22:15 UTC

…but are no higher than unpolluted clouds when imbedded in **closed cellular** stratus



# Differences in Cloud Depth (Ship – Controls)

<u># of cases :</u> Closed Celled: **141** Open Celled: **32 May 2010 – number is rapidly increasing**

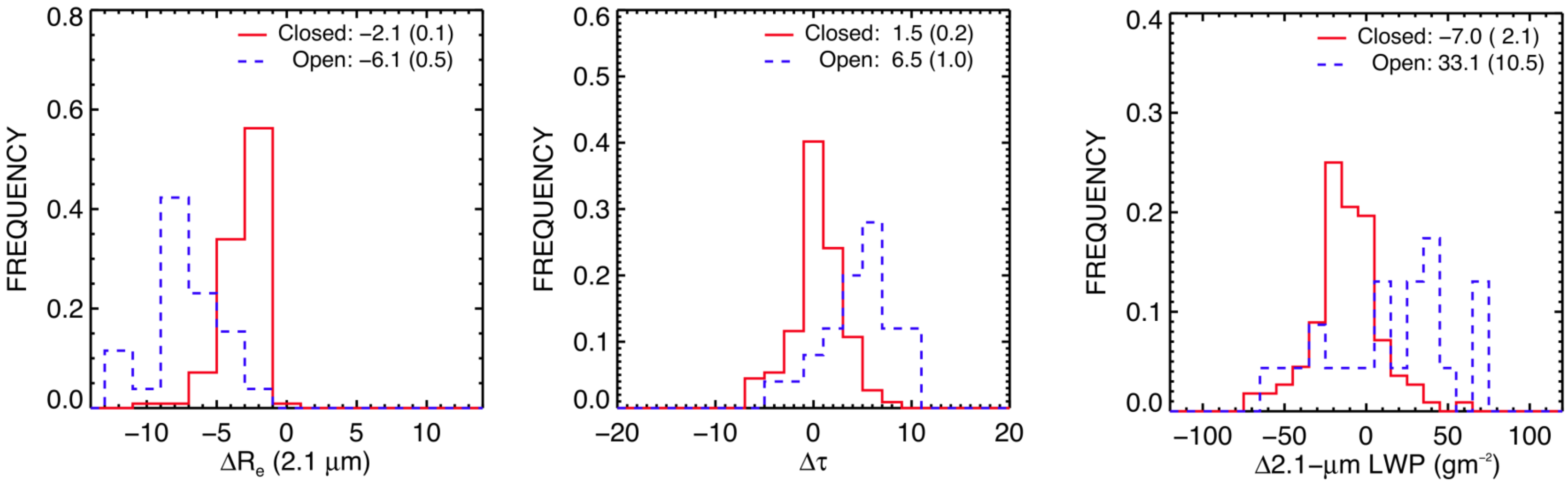



**Height differences are *most* pronounced under low static stability, high moisture content above the boundary layer, and low cloud cover fraction.**

**Polluted clouds in open celled convection are ~15% deeper than the unpolluted clouds.**

**Aerosol has the largest impact on cloud depth in the open cell regime but virtually no impact on cloud depth in the closed cell regime.**

# Differences in Cloud Optical Properties




**Polluted clouds have smaller droplet sizes as predicted by the "Twomey Effect" and is more pronounced in open cell clouds.**

**Polluted clouds have enhanced cloud optical depths.**

**The deeper polluted clouds in open cell convection have *larger* liquid water amounts. In an unstable and relatively moist environment suppressed precipitation enables clouds to grow deeper and accumulate more liquid water than nearby unpolluted clouds (Pincus and Baker, 1994).**

# Implications for aerosol indirect forcing

The change in cloud albedo is given by

$$\Delta\alpha_c = \alpha_c(1-\alpha_c)\frac{\Delta\tau_c}{\tau_c}$$

where, $\alpha_c$ is the cloud albedo and $$ is the fractional change in optical depth.

Aerosol has a larger impact on the radiative properties of open cell clouds than closed cell clouds.

Cloud Albedo Changes

| | Closed Cell | Open Cell |
|---|---|---|
| Δα | 0.03 | 0.15 |
| ΔF | 12 W/m$^2$ | 58 W/m$^2$ |

*Assuming an incoming solar radiative flux of 400 W/m$^2$

$$\frac{\Delta\tau_c}{\tau_c} = -\left(\frac{\Delta R_e}{R_e} - \frac{\Delta LWP}{LWP}\right) \propto \frac{\Delta\alpha_c}{\alpha_c}$$

Micro-Macro physical terms

| | Closed Cell | Open Cell |
|---|---|---|
| ΔRe/Re | -0.18 | -0.28 |
| ΔLWP/LWP | -0.07 | +0.29 |

Closed Cell: primarily microphysical
Open Cell: BOTH

The change in cloud albedo is given by

$$\Delta\alpha_c = \alpha_c(1-\alpha_c)\frac{\Delta\tau_c}{\tau_c}$$

where, $\alpha_c$ is the cloud albedo and $$ is the fractional change in optical depth.

Aerosol has a larger impact on the radiative properties of open cell clouds than closed cell clouds.

Cloud Albedo Changes

| | Closed Cell | Open Cell |
|---|---|---|
| Δα | 0.03 | 0.15 |
| ΔF | 12 W/m² | 58 W/m² |

*Assuming an incoming solar radiative flux of 400 W/m²

$$\frac{\Delta\tau_c}{\tau_c} = -\left(\frac{\Delta R_e}{R_e} - \frac{\Delta LWP}{LWP}\right) \propto \frac{\Delta\alpha_c}{\alpha_c}$$

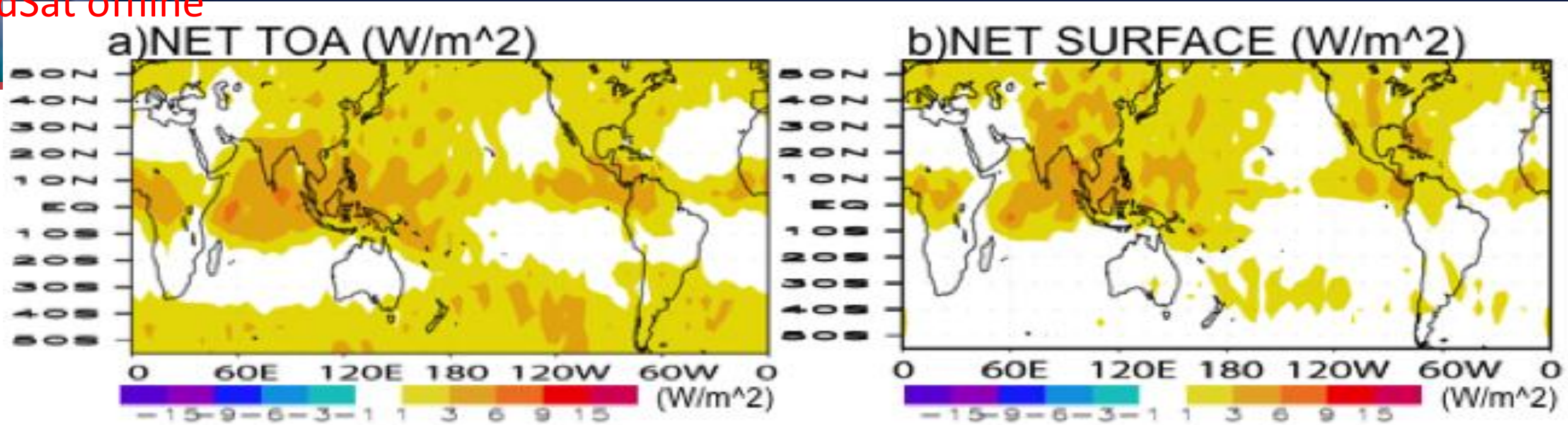
Micro-Macro physical terms

| | Closed Cell | Open Cell |
|---|---|---|
| ΔRe/Re | -0.18 | -0.28 |
| ΔLWP/LWP | -0.07 | +0.29 |

Closed Cell: primarily microphysical
Open Cell: BOTH

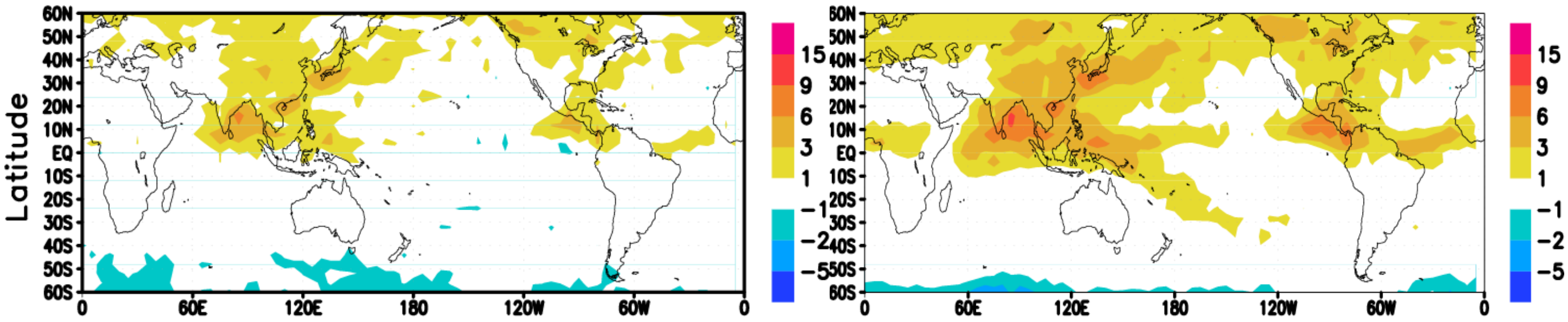
# Net radiative effects: No snow-radiation – Control(with)

CloudSat offline

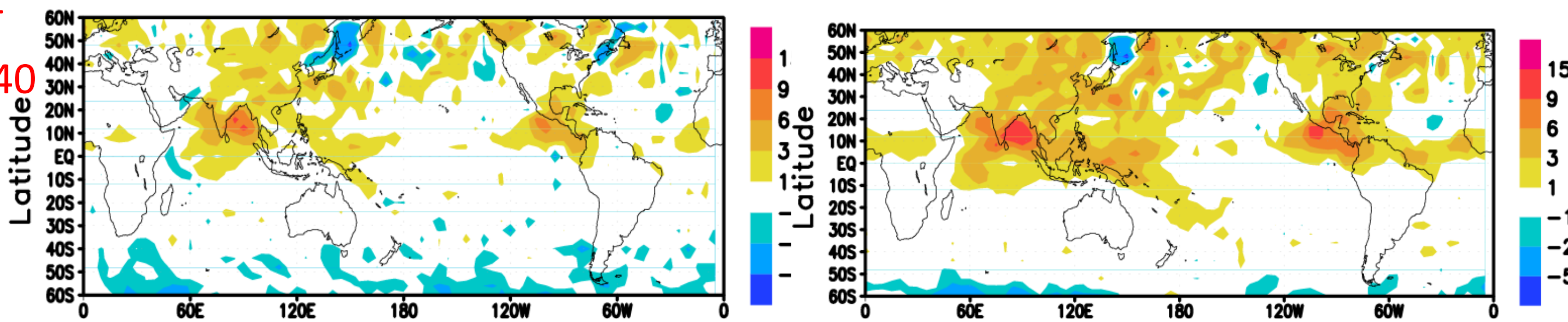



**(Waliser, Li and L'Ecuyer, 2010)**

EC FCST
24to48



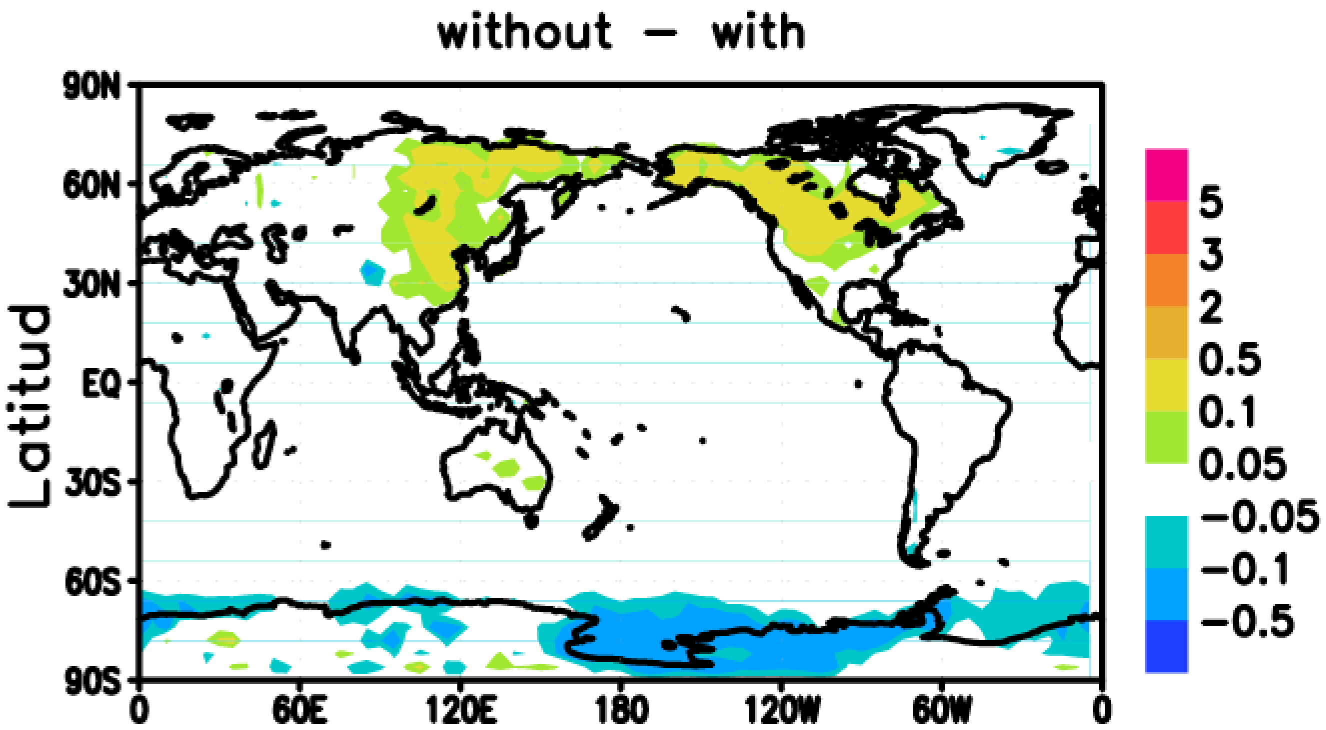

EC FCST
120to240




**(Li, Waliser and Forbes, 2010)**

# Net radiative effects: No snow-radiation – Control(with)

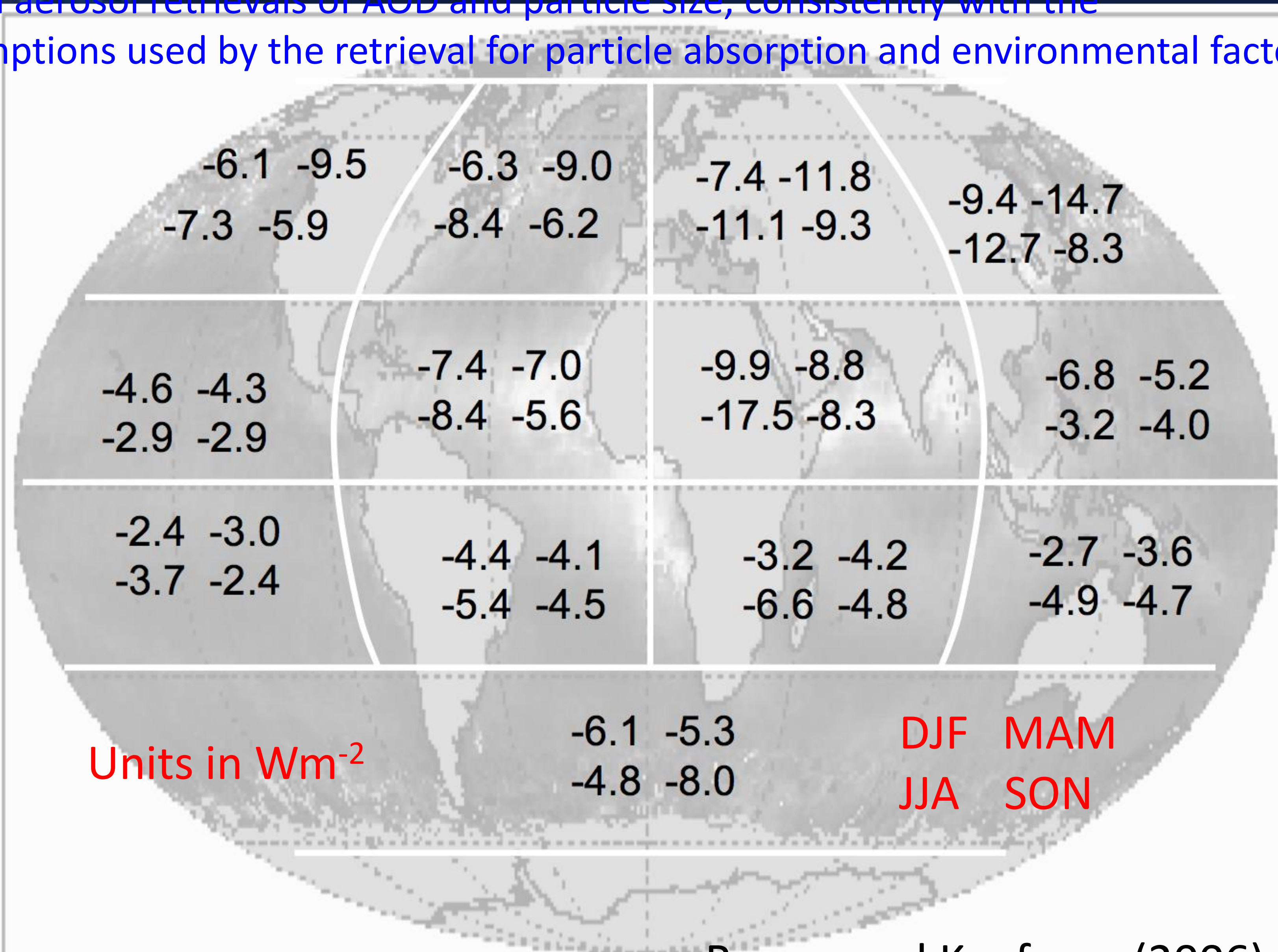
Skin temperature
EC FCST 24to48 @ 00Z time



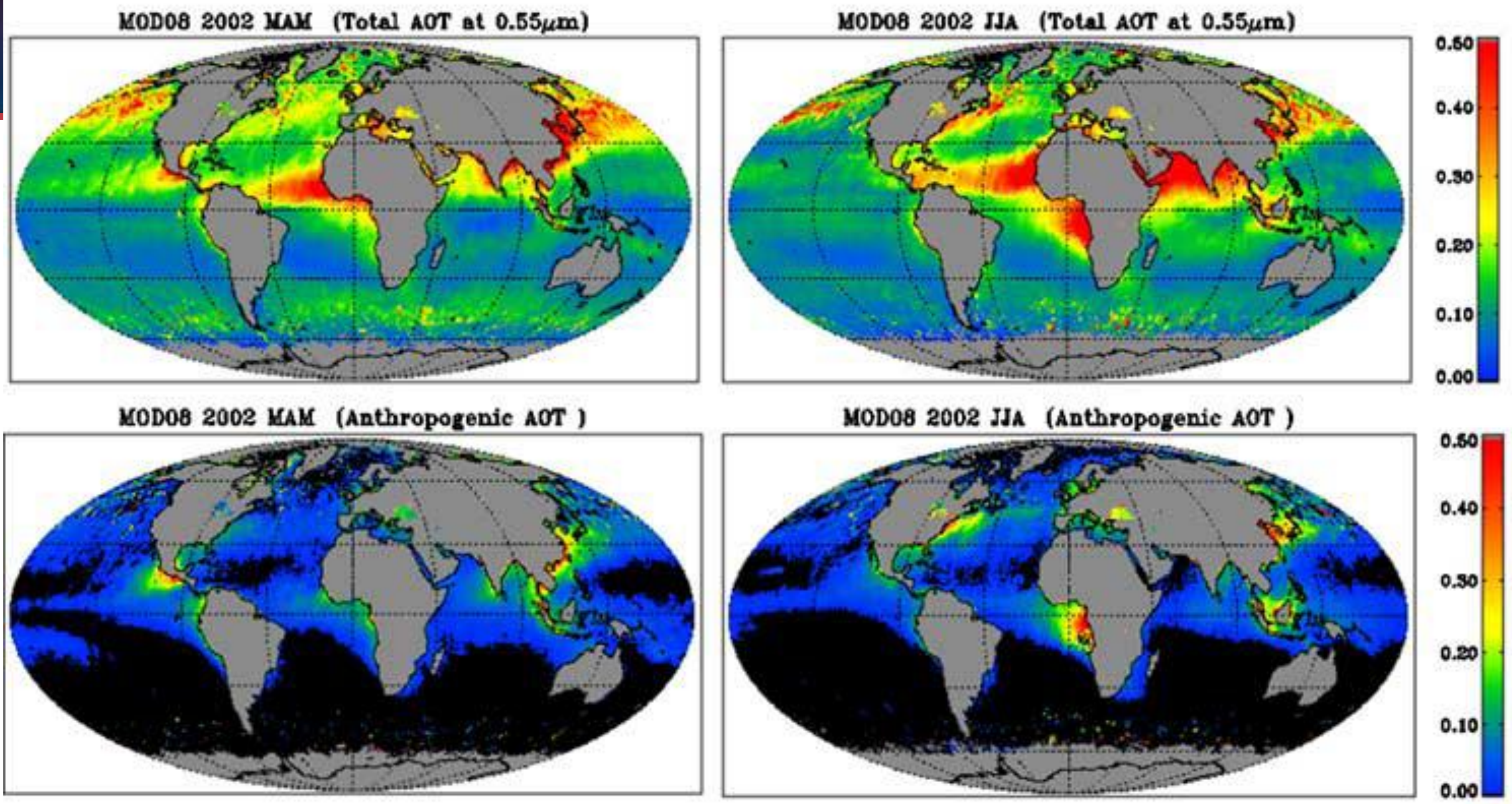



**(Li, Waliser and Forbes, 2010)**

Calculations of direct radiative effect over ocean for regions and seasons using MODIS ocean aerosol retrievals of AOD and particle size, consistently with the assumptions used by the retrieval for particle absorption and environmental factors.




Remer and Kaufman (2006) ACP

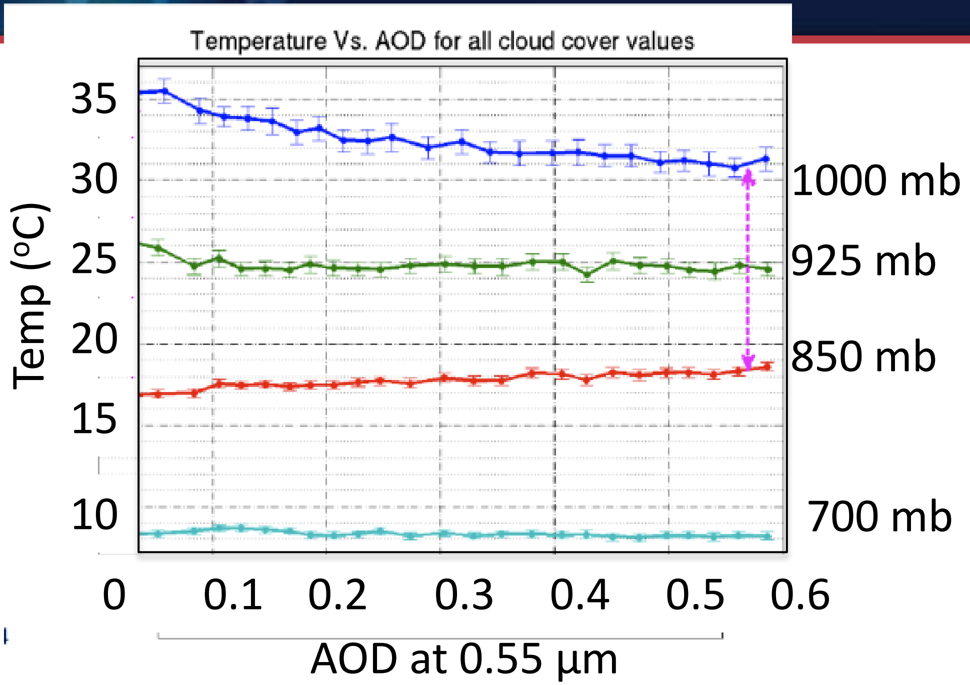



Assuming all combustion particles are anthropogenic, by using results from the MODIS over ocean aerosol retrieval, we can estimate the anthropogenic AOD. From that and calculations of the aerosol effect on previous slide we estimate the anthropogenic forcing over the global oceans to be $-1.4 \pm 0.4\ Wm^{-2}$

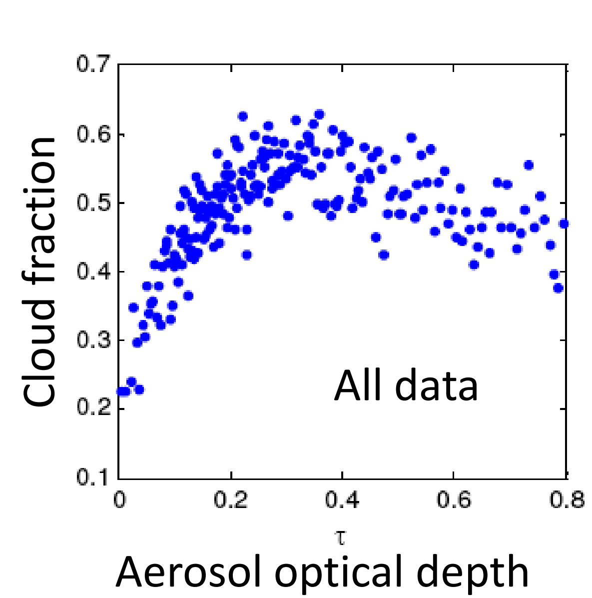
Kaufman et al., (2005) GRL

# Semi direct effects

Davidi et al., (2009) ACP




Koren et al. (2008) Science

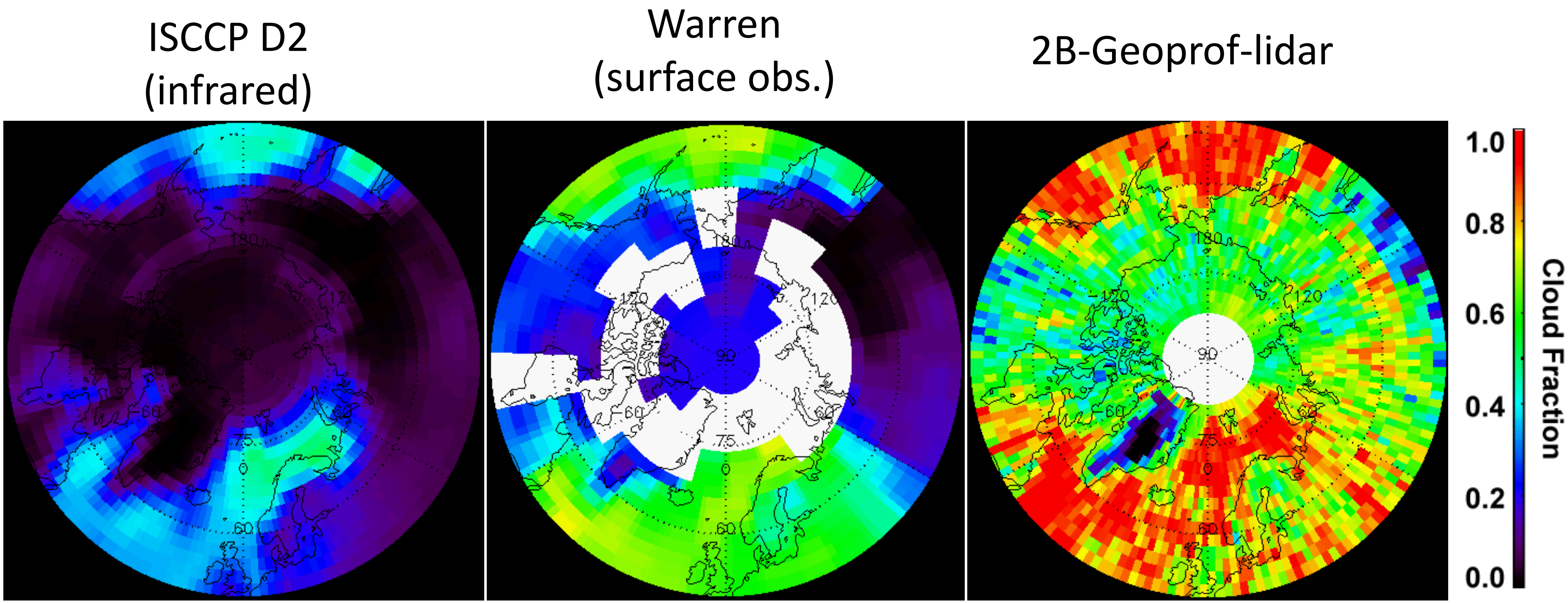



Absorbing aerosol can warm layers of the atmosphere as well as play a role in changing cloud microphysics.

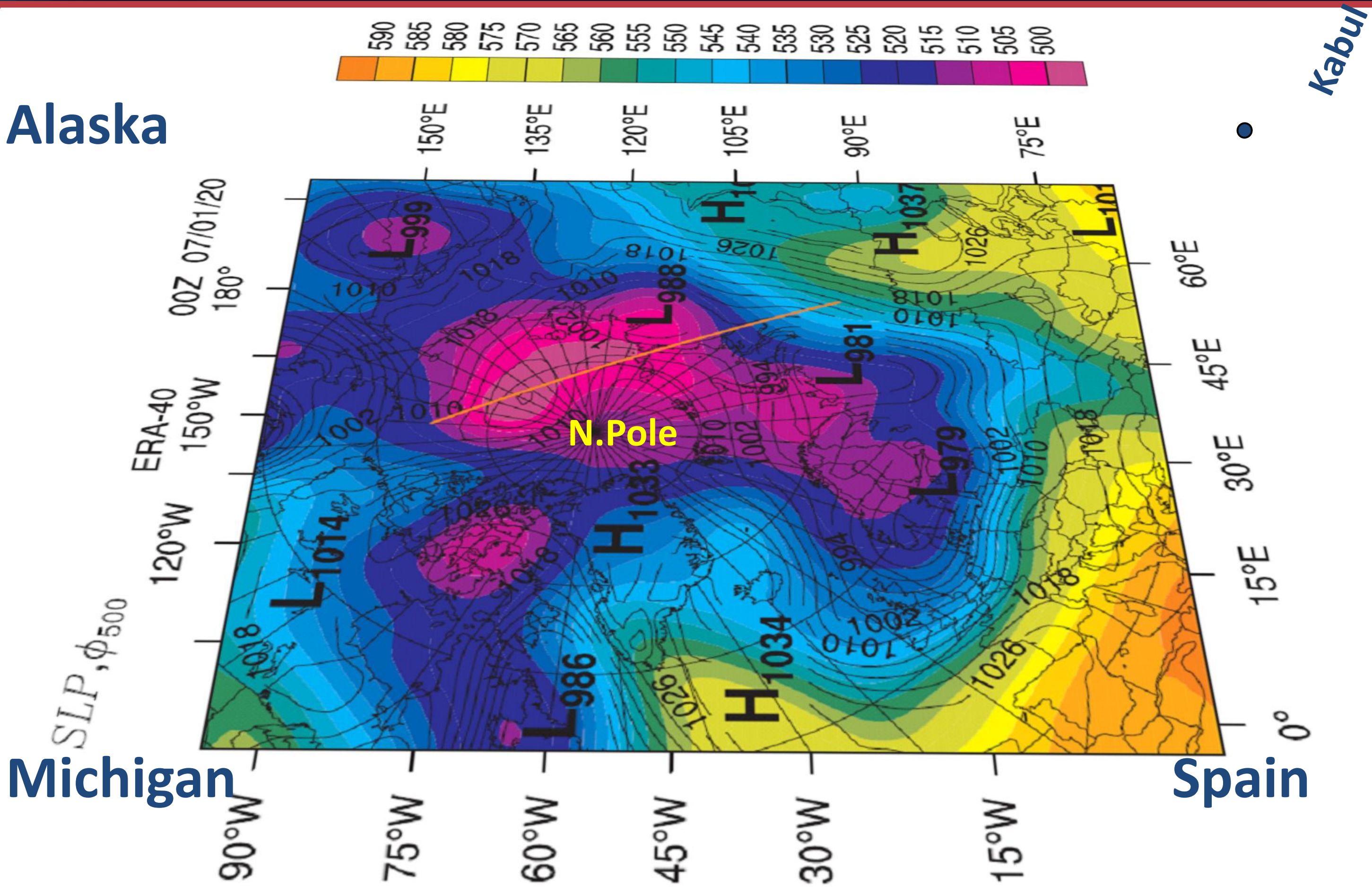
Here MODIS + AIRS data can show us the associations between cloud, aerosol and temperature profiles. These offer us hypotheses to test, but are missing rigorous quantitative information about the distribution of absorbing aerosol and heating rates in the vertical.

# 3b) Polar (night) Arctic clouds.

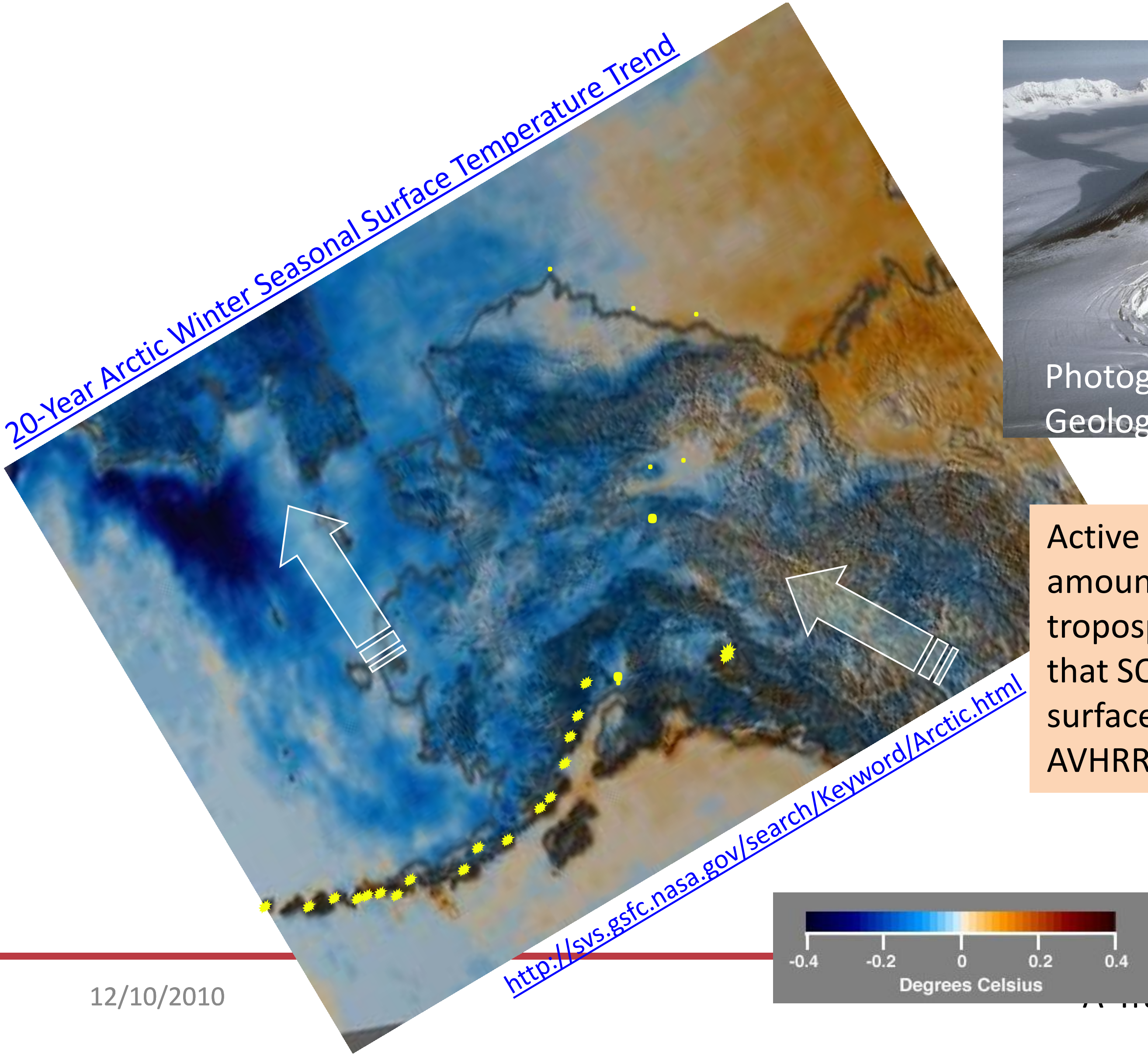
*DJF Low Cloud Maps*



# i) Wintertime storms



# ii) Sulphur Sources and AVHRR Arctic (Wintertime) Temperature Trend




Photograph by M.E. Yount, U.S. Geological Survey, January 23, 1984.

Active Aleutian volcanoes emit large amount of sulphur in the lower troposphere. This is a strong indication that $SO_2$ – $SO_4$ sources are affecting surface temperatures trends shown in AVHRR.

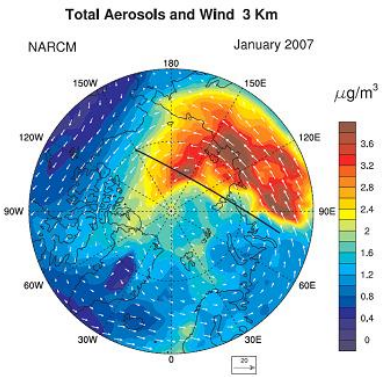
Blanchet et al., 2010

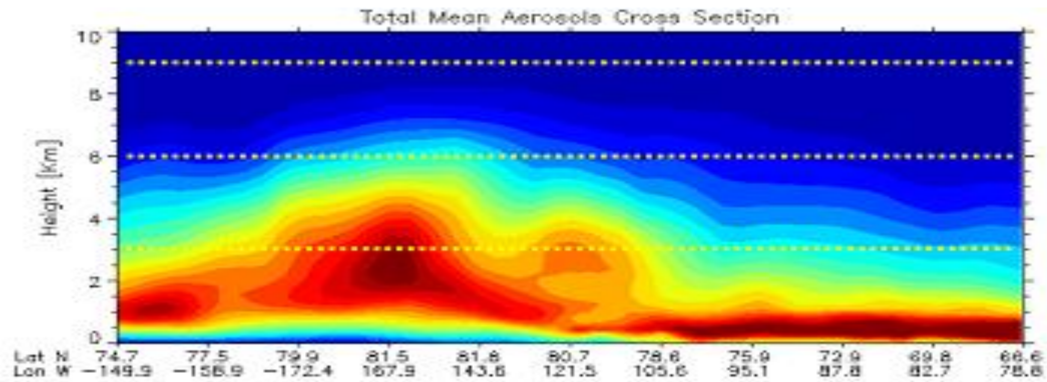


http://nationalatlas.gov/dynamic/dyn_vol-ak.html

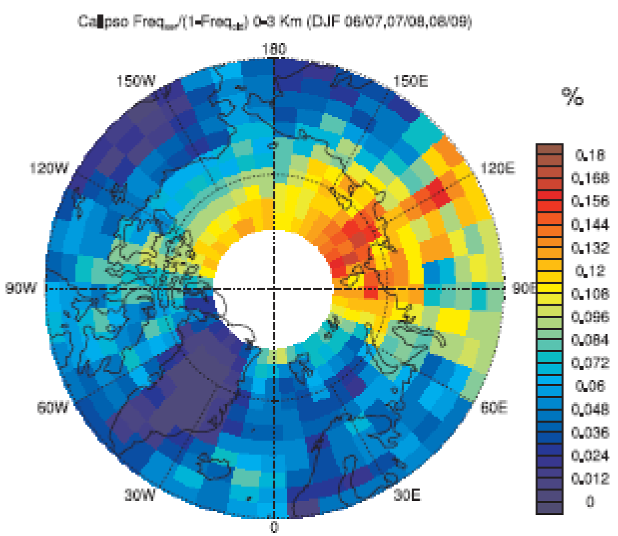
# iii) Pollutants Lifted in Cold Regions

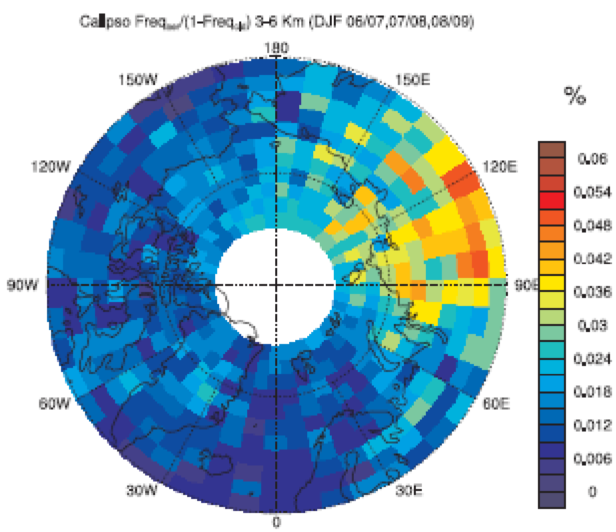
Simulated NARCM

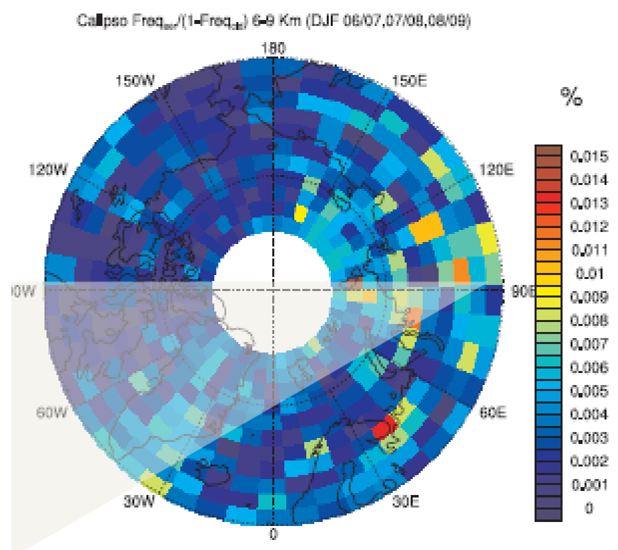



Observed CALIPSO



# iv) Pollution inhibits nucleation

Manmade acid coating of natural dust

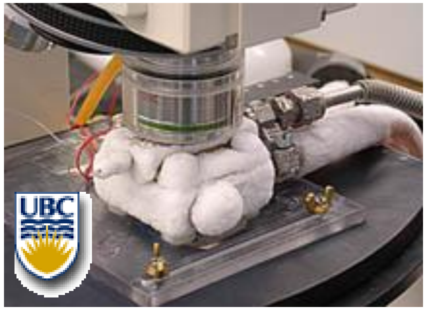
*Ref.: Bigg, 1980*

Ice crystal nucleation on acid coated aerosols


*Ref.: Bertram, 2008*

## In Laboratory

Allan Bertram at UBC

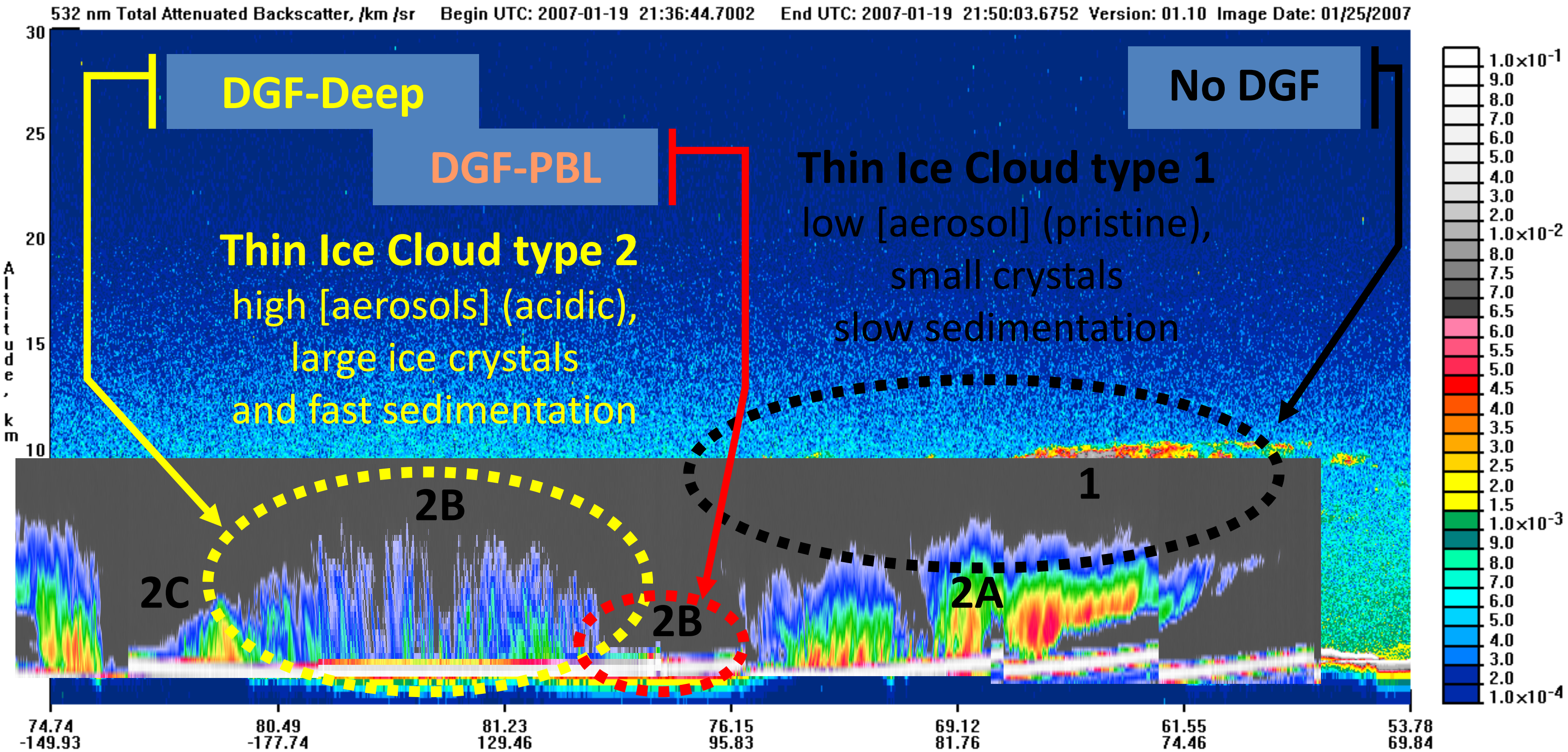


**Flow cell coupled to microscope**

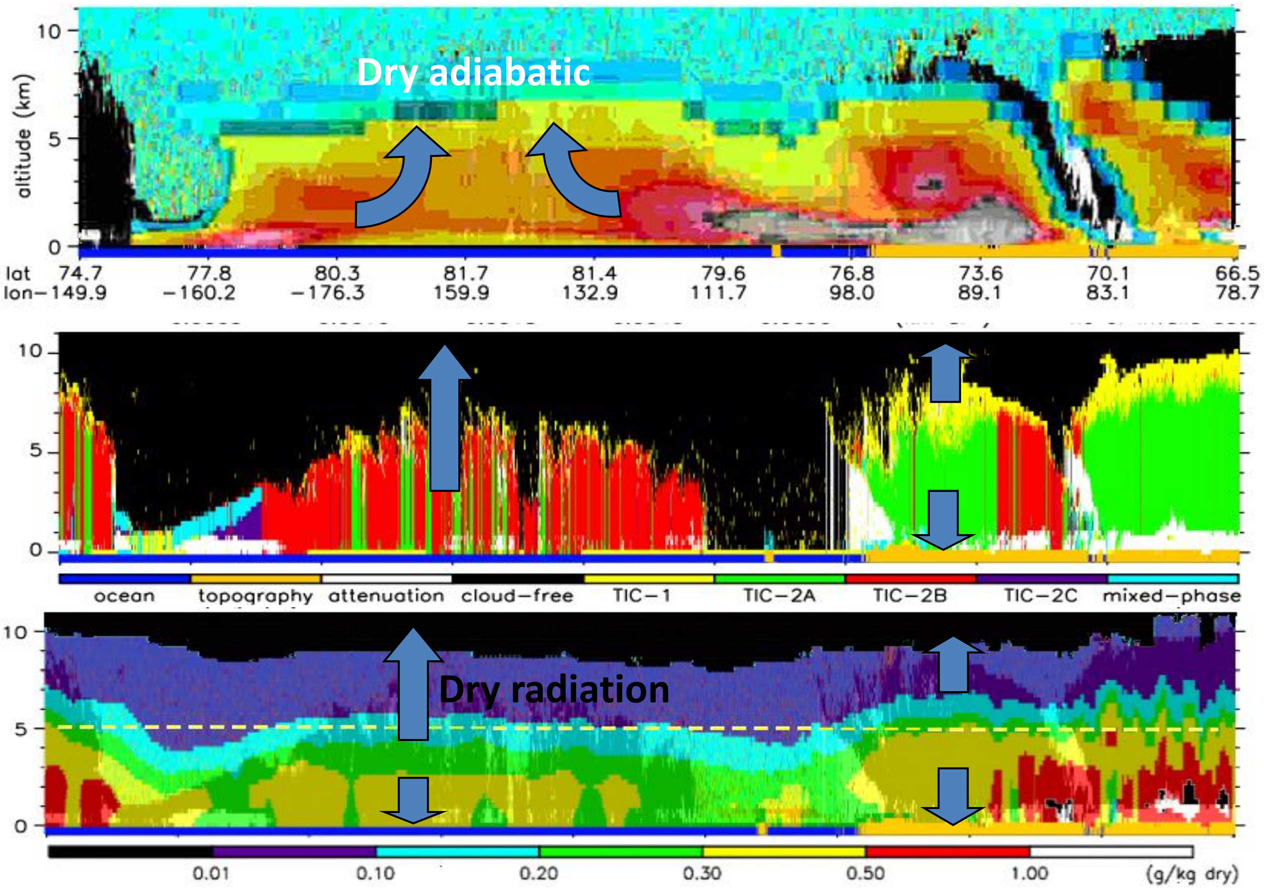
# In this environment clouds look different

January 19, 2007

Radar – Lidar DGF Signature



# Rapid & sustained cooling of airmass




**Process #1: Dynamics**

**DT ≈ -10 to -20°C**

Time scale ~ 1day

**Process #2: Direct IR**

**DT ≈ -16 to +10°C**

Time scale: 1 to 5 days

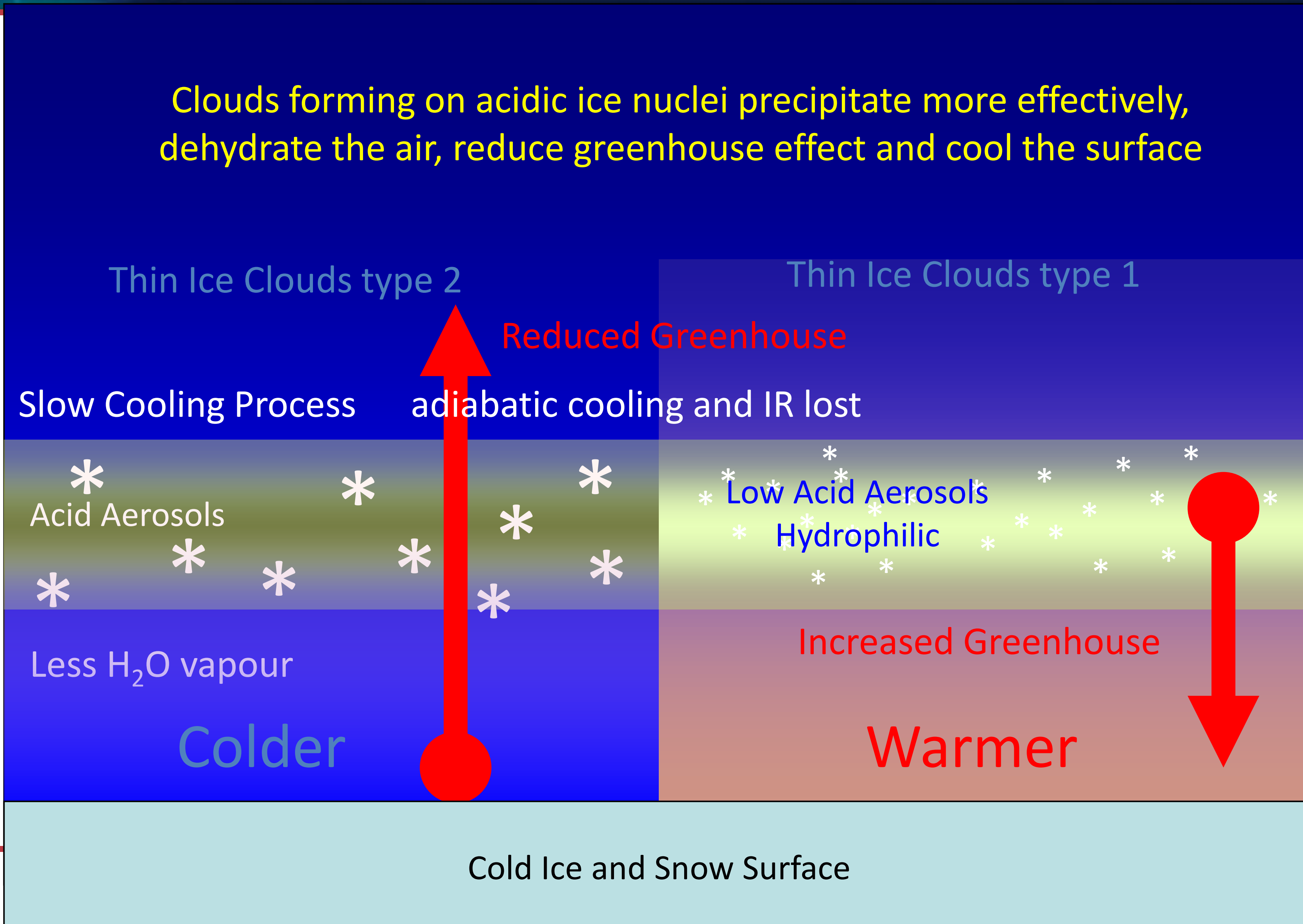
**Process #3: Indirect IR**

**DT ≈ -5 to -10°C**

Time scale: 1 to 2 weeks

**Total Cooling ≈ -30 to - 50°C**

# Dehydration-(reverse)Greenhouse Feedback (DGF)



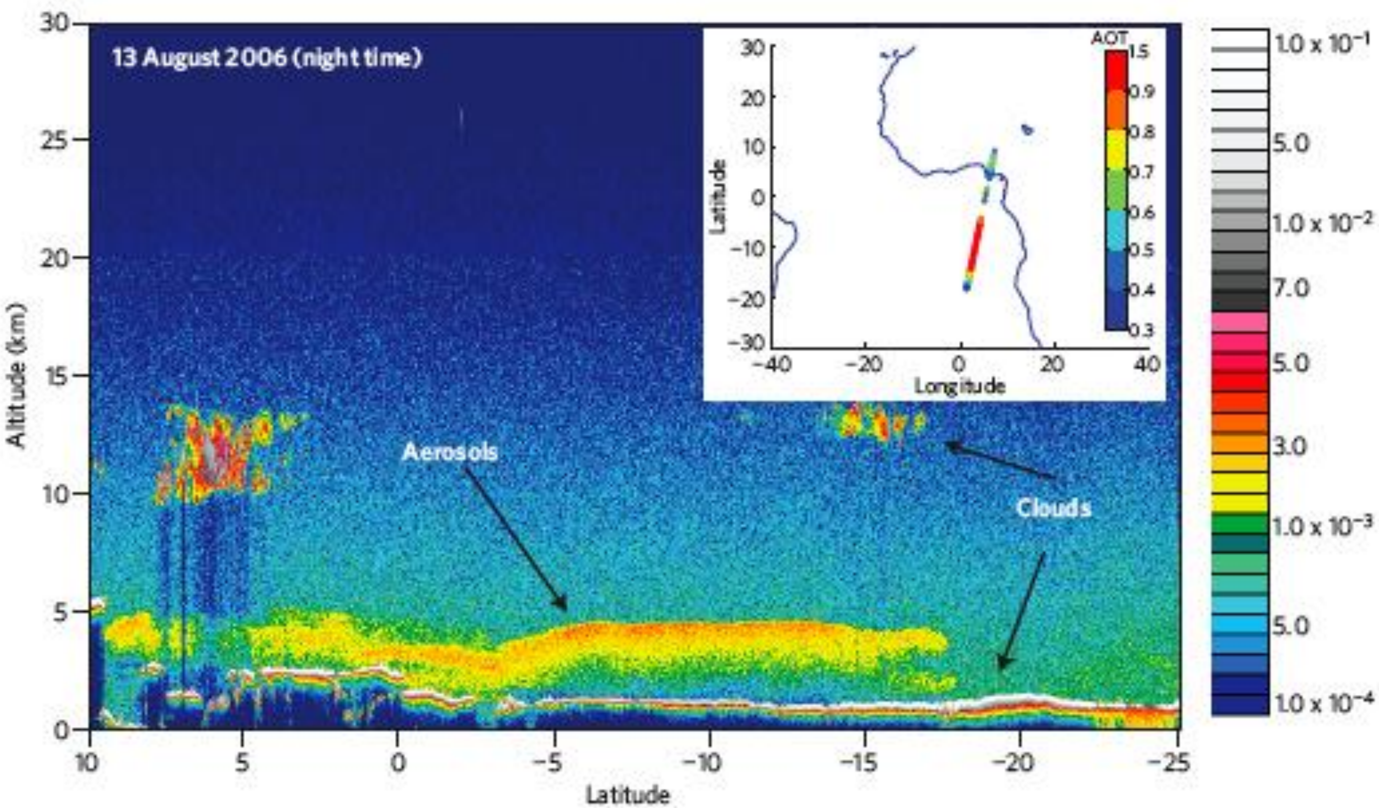
# A-Train: 1. Aerosol forcing above cloud

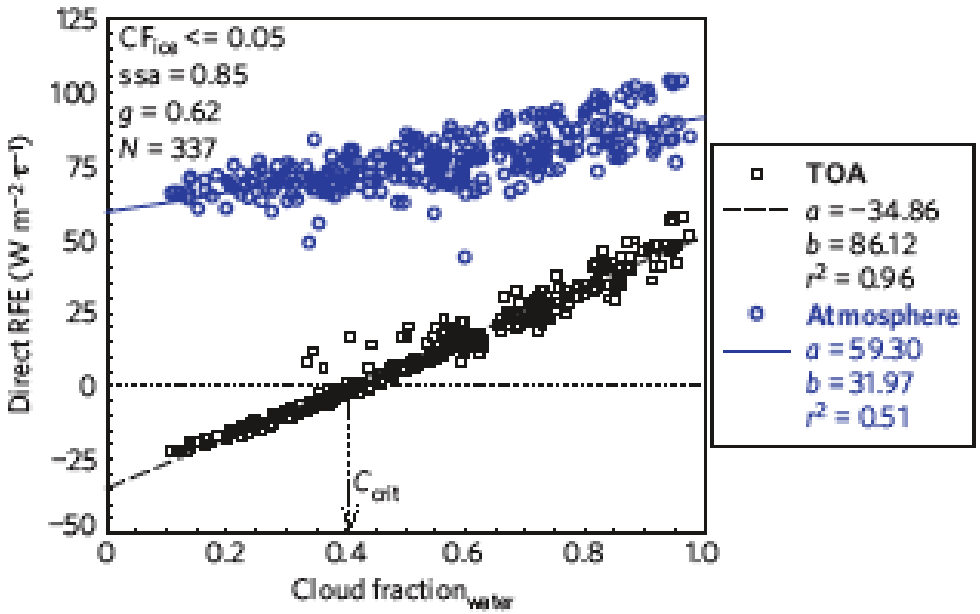
**Background**: Aerosols from biomass burning can alter the radiative balance of the Earth by reflecting and absorbing solar radiation. Whether aerosols exert a net cooling effect (decreased reflected sunlight) or a net warming effect (increased reflected sunlight) depends on the aerosol type and the albedo of the underlying surface.

**Underlying Hypothesis**: There is a substantial amount of aerosol warming that occurs due to the presence of aerosol above cloud that greatly influences global estimates of aerosol forcing.

**Enabling Measurements**: CALIPSO lidar combined with MODIS produces the first unambiguous measurements of the existence of aerosol above clouds.

**Example of biomass aerosol above low cloud**





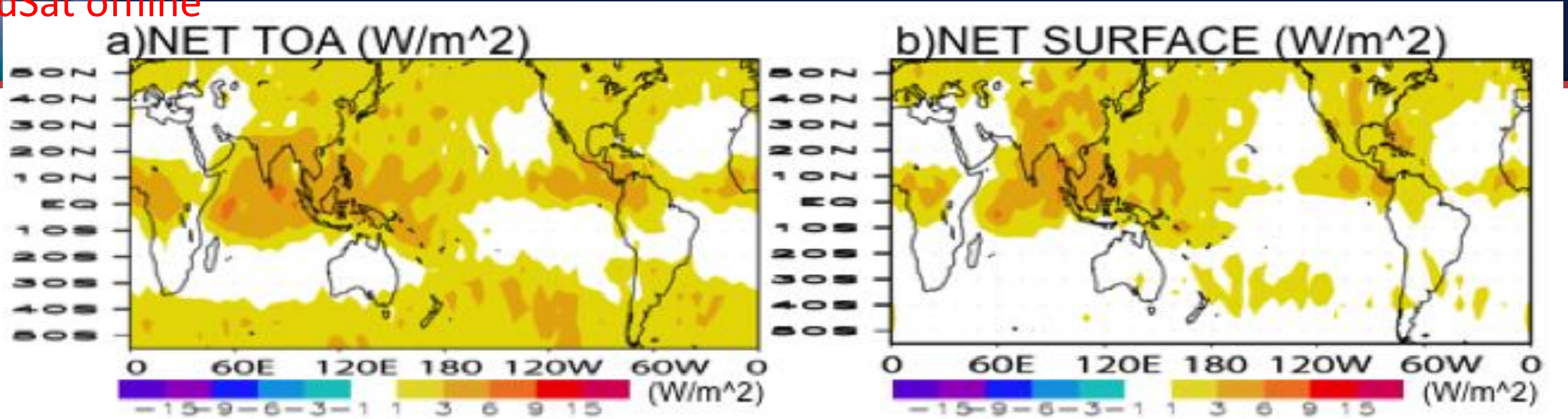

The change in direct aerosol radiative forcing efficiency (black) as a function of the fraction of cloud below. The aerosol forcing changes from negative (cooling) to positive (warming) as cloud cover increases

**Why relevant – the bigger picture**: - Aerosol forcing is a key uncertainty in the prediction of climate change. The sign and magnitude of this forcing depends on the type of underlying surface below the aerosol. There are large differences in the aerosol forcing used in climate models particularly in regions of clouds, varying from -1 to +2 $Wm^{-2}$ in the region of this study. Aerosol forcing in these regions have been poorly constrained by traditional data sources that are restricted to identifying aerosols only in clear-sky situations.

**Key Reference(s):** Chand et al., 2009

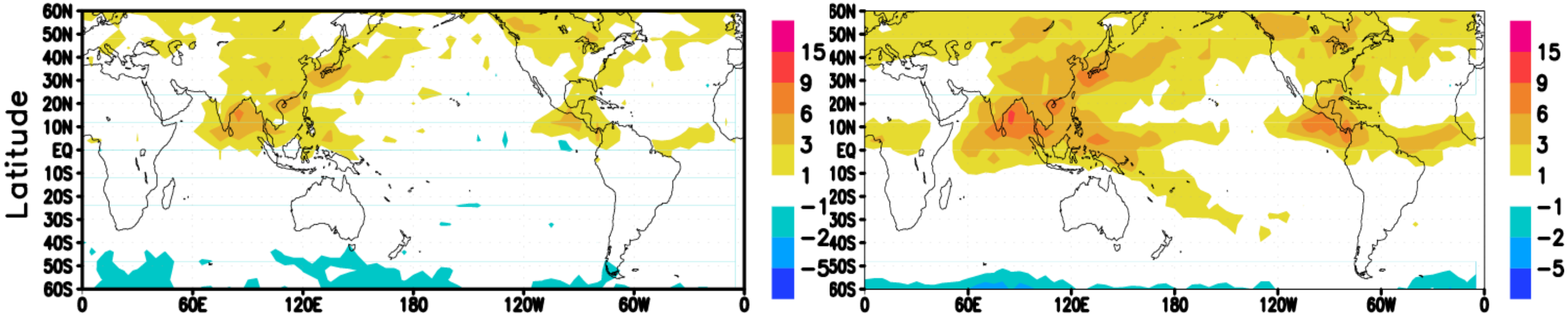
# Net radiative effects: No snow-radiation – Control(with)

CloudSat offline

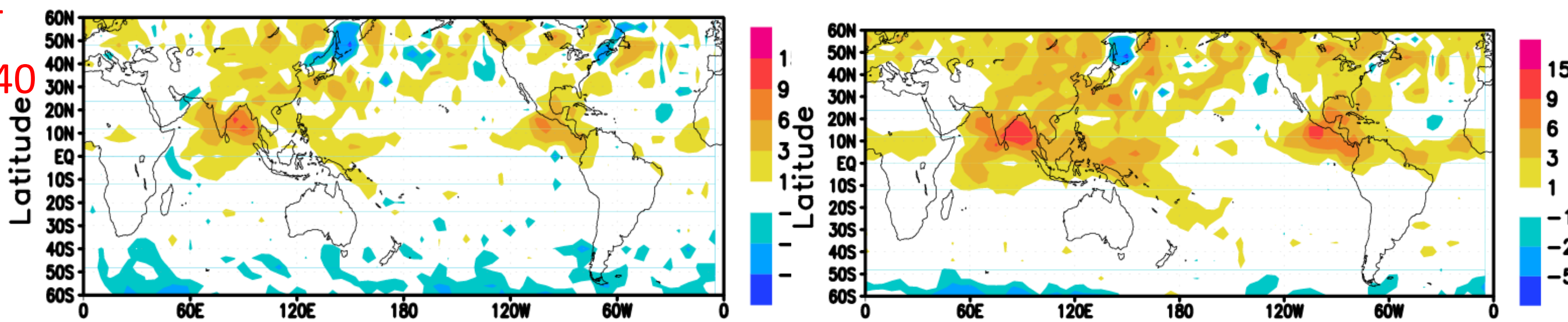



(Waliser, Li and L'Ecuyer, 2010)

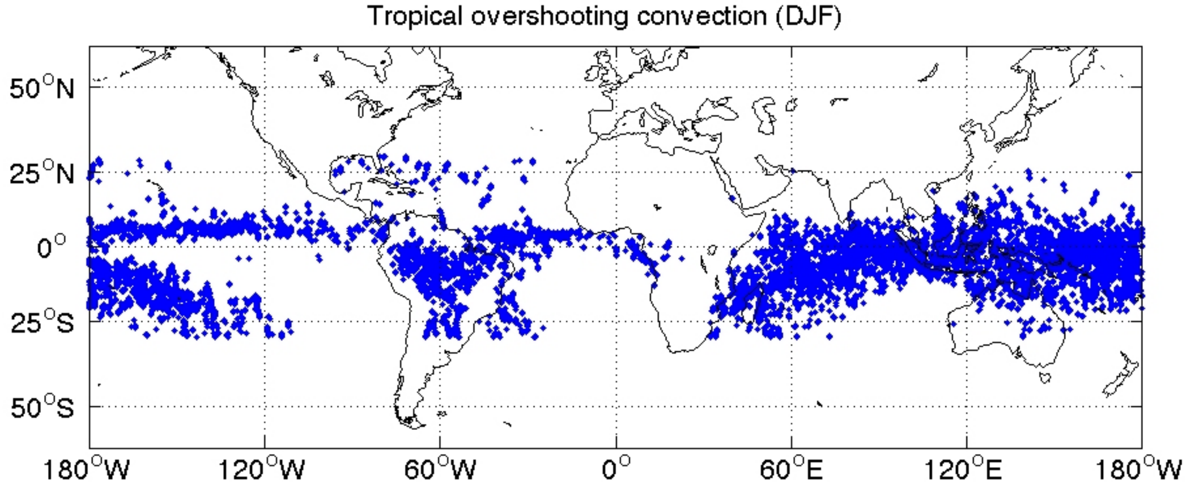
EC FCST 24to48

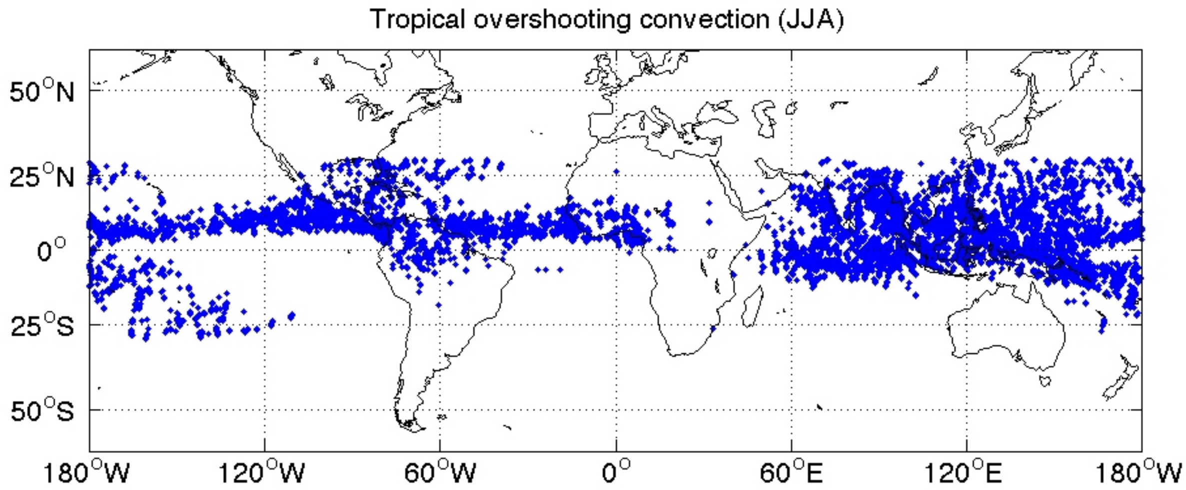



EC FCST 120to240




(Li, Waliser and Forbes, 2010)



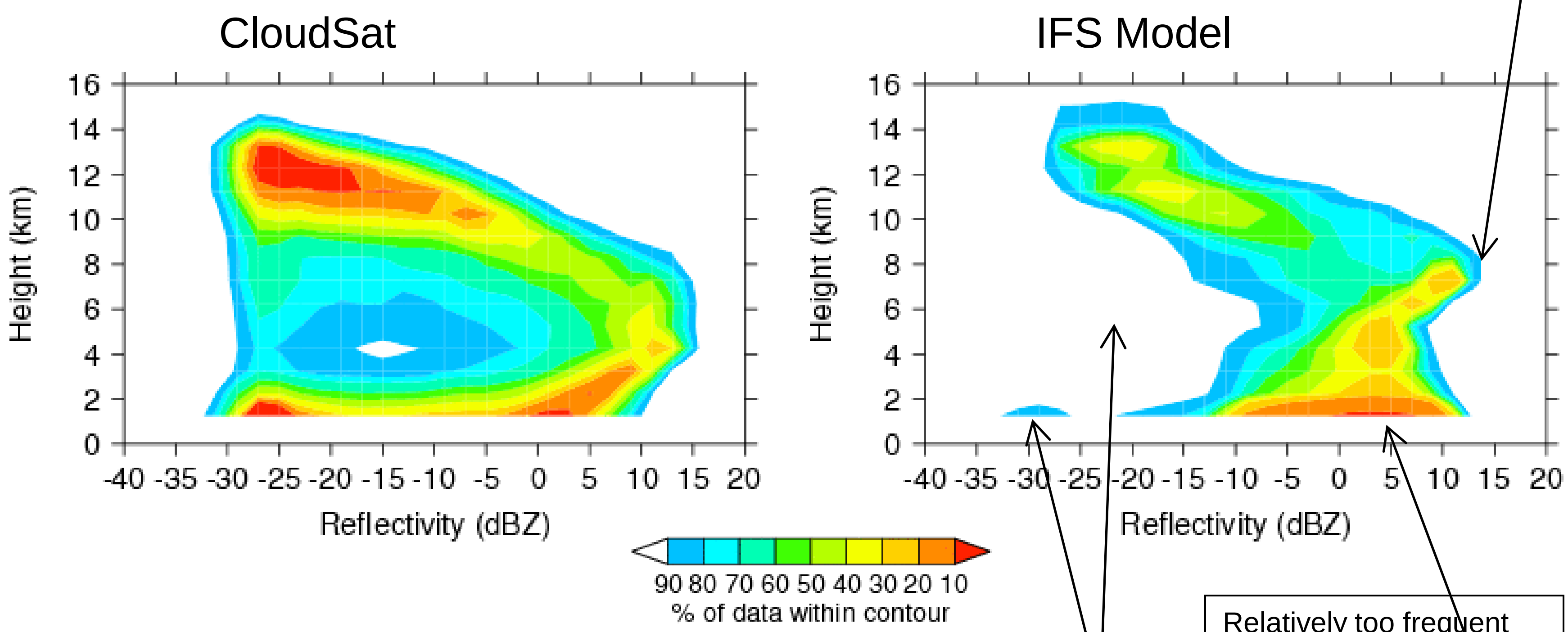

0.08% of tropics occupied by 'hot-towers' convection

# More evidence of problems with rain process as parameterized in models

## Radar Reflectivity vs. Height
## Relative Frequency of Occurrence

Tropics over ocean 30S to 30N for February 2007

Peak reflectivities too high altitude




Lack of low reflectivity mid-level and low-level cloud ?

Relatively too frequent low-level high reflectivity convective & L-S rainfall

Similar also in UKMO UM
Salcedo-Bodas, 2008

# GFDL precipitation biases